Detailed Description for CE-5

En Route Free Maneuvering

Charles T. Phillips

TITAN SYSTEMS CORPORATION

SRC DIVISION

Preface

This report is the first version of a detailed description for the Distributed Air/Ground Traffic Management (DAG-TM) Concept Element (CE) 5, En Route Free Maneuvering. The ideas presented here are preliminary and require additional work, in particular as related to the air traffic control ground concept to support airborne operations.

NASA is soliciting review of this report and welcomes comments. Comments should be sent to:

- Del Weathers, Manager, AATT ATM Concept Definition Sub-element, NASA Ames Research Center – dweathers@mail.arc.nasa.gov
- Mark Ballin, Manager, and David Wing, Lead Engineer, AATT Aircraft Systems and Operations Sub-element, NASA Langley Research Center – m.g.ballin@larc.nasa.gov; d.j.wing@larc.nasa.gov

Acknowledgement

Table of Contents

1. Introduction

1.1 Background

The Distributed Air/Ground Traffic Management (DAG-TM) concept describes potential modes of operation within the Free Flight concept defined by the RTCA Task Force 3. The goal of DAG-TM is to enhance user flexibility and efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the National Airspace System (NAS).

To explore the DAG-TM concept, the AATT Project formed a DAG-TM Team which met during 1999 and developed a Concept Definition.[1] This document defined 15 DAG-TM "concept elements", covering ATM operations in all phases of flight. The defined phases were:
* Gate-to-Gate (information access and exchange)
* Pre-Flight Planning
* Surface Departure
* Terminal Departure
* En Route
* Terminal Arrival
* Terminal Approach
* Surface Arrival

In 2000, the AATT Project selected an initial set of four concept elements (CEs) to pursue further concept exploration (research) activities.
* CE-5: En Route Free Maneuvering
* CE-6: En Route Trajectory Negotiation
* CE-7: En Route: Collaboration for Mitigating Local TFM Constraints due to Weather, SUA, and Complexity
* CE-11: Terminal Arrival: Self-Spacing for Merging and In-Trail Separation

In May 2000, a DAG-TM Workshop was held at the NASA Ames Research Center to explain to industry the AATT Project's activities and plans for the concept. The workshop focus was on the four initial CEs being developed. Under Task Order 41, a contractor team consisting of System Resources Corporation and Seagull Technology is preparing detailed descriptions of each of the four selected CEs. This document is a detailed description of objectives and operational concepts for CE-5, En Route Free Maneuvering.

1.2 Objectives

This detailed description has the following objectives:
* It provides technical transfer and sharing of information within the NASA research community. It is intended to capture the current thinking of NASA researchers concerning the future ATM environments and capabilities that may be created by this concept.
* It is a guide for a planned program of research in this concept through 2004.
* It is consistent with and amplifies the DAG-TM concept definition.
* It is consistent with AATT objectives as described in the AATT Air Traffic Management Operations Concept (ATM/OPSCON).

- It is a living document intended to be continually updated as the research program progresses, with expected convergence on a feasible and viable concept that provides system-wide benefits.

1.3 Scope

This CE-5 description is intended to provide enough detail to form a basis for further research into the concept. It is not, however, a research plan. The research plan is a separate document being developed by NASA which describes how the concepts presented here will be investigated, and how statements presented here as hypotheses will be tested.

The description has a focus of operational and system requirements, and deliberately avoids design information to the extent possible. The NASA Langley Research Center is in the process of designing automated airborne systems to test the CE-5 concept, including the Autonomous Operations Planner (AOP) which will function on board free maneuvering aircraft. The description is consistent with, and provides additional guidance to, these design efforts.

Finally, specifications are omitted from this document, since capabilities to support the CE-5 concept should evolve as a result of the research to be conducted. To avoid confusion with widely discussed tools such as ADS-B or CPDLC whose specifications are being developed or discussed, this description uses general terms to describe the capabilities necessary to support the concept.

2. Problem Description

This section describes today's problems, followed by a discussion of the root sources of today's problems. The foundation document for the high-level discussion of today's problems below is the AATT Concept Definition for DAG-TM,[1] and the problem statements from that document are taken here as assumptions.

2.1 Today's Problems

In today's en route airspace environment, many aircraft must fly non-optimum routes because of deviations from the user-preferred path. These inefficiencies result mainly from either conflict situations with other traffic or from conformance with local traffic flow management (TFM) constraints. However, often the deviations from the optimum path do not meet user preferences or are excessive. The focus of both CE-5, En Route Free Maneuvering, and CE-6, En Route Trajectory Negotiation, is the investigation of and proposed solution to two of the problems leading to these excessive or non-preferred deviations. As stated in the Concept Definition for DAG-TM:

(a)   ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current ATC system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers to allow them to pay less attention to each situation. Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary "resolution" of false alarms (i.e., predicted "conflicts" that would not have materialized had the aircraft continued along their original trajectories). In those cases where a conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and displays), and also to a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b)   ATSP often cannot accommodate the user's (flight crew or AOC) trajectory preferences for conformance with local traffic flow management (TFM) constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (flight crew or AOC) is required to submit a request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (airspace congestion, arrival metering/spacing) can result in the flight crew or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences.

Further negotiation between the ATSP and flight crew can adversely impact voice-communication channels and increase workload for both.

2.2 Root Sources of Today's Problems

The above high-level problem descriptions are related, in that they both cause the user to deviate from a user-preferred path. The following characteristics of the present system cause these excessive or unnecessary deviations: trajectory prediction uncertainty, ATSP workload limitations, and lack of user preference knowledge.

2.2.1 Trajectory Prediction Uncertainty

To solve anticipated air traffic conflict situations, future aircraft trajectories must be predicted. The accuracy of these predictions determines the breadth of resolution options available. If trajectory predictions are inaccurate, resolution options involving legal, but closer separation are unavailable. These limitations in resolution options contribute to deviations from user-preferred trajectories. Instead of a user being able to fly a user-preferred trajectory with small deviations for traffic constraints, the user may have to fly a trajectory with much larger deviations to accommodate the uncertainty of the aircraft's trajectory as well as other traffic trajectories.

2.2.1.1 Cause of Trajectory Prediction Uncertainty

Certain characteristics of current air traffic systems are the cause of trajectory prediction uncertainty. The first is that trajectory adjustments made while en route are based on a sector-oriented viewpoint, as opposed to a whole-trajectory viewpoint. This segregation of a trajectory into sector-defined portions means that trajectory adjustments that will be made in future sectors are difficult to predict.

A second cause of uncertainty is the lack of accurate future information about the air traffic environment. First, the actual trajectories followed by aircraft are often not known in the future, because the trajectories will change due to unanticipated conflicts. Second, airspace restriction areas due to weather or congestion are not known accurately because of the dynamic nature of these area hazards. Third, there is imperfect knowledge of wind fields. Fourth, future aircraft intent information is not readily accessible. Within a given sector, a controller can anticipate the resolution maneuvers that will be needed, and, therefore, the intent of the aircraft. However intent information for downstream sectors is not readily accessible, since different controllers are involved in resolutions for these sectors. Lastly, future trajectory predictions are not displayed effectively. Currently, the ATSP has access to a tool that shows a projection of an aircraft's predicted path for a short look-ahead time, but not for an entire trajectory.

2.2.1.2 Effect of Trajectory Prediction Uncertainty

One effect of trajectory prediction uncertainty is the implementation of larger-than-necessary buffers for protected zones around aircraft for separation assurance. Because the future trajectory is uncertain, extra distance is added to the normal protected zones. This extra uncertainty buffer results in a separation well beyond the protected zones as illustrated in Figure 1.

Also, trajectory prediction uncertainty may cause excessive resolution maneuvers. Resolutions are made to avoid not only normal protected zones, but also extra uncertainty buffers. Although

these solutions are robust, they also cause maneuvers that may be larger than necessary for legal separation assurance and further deviate a user from the user-preferred path.
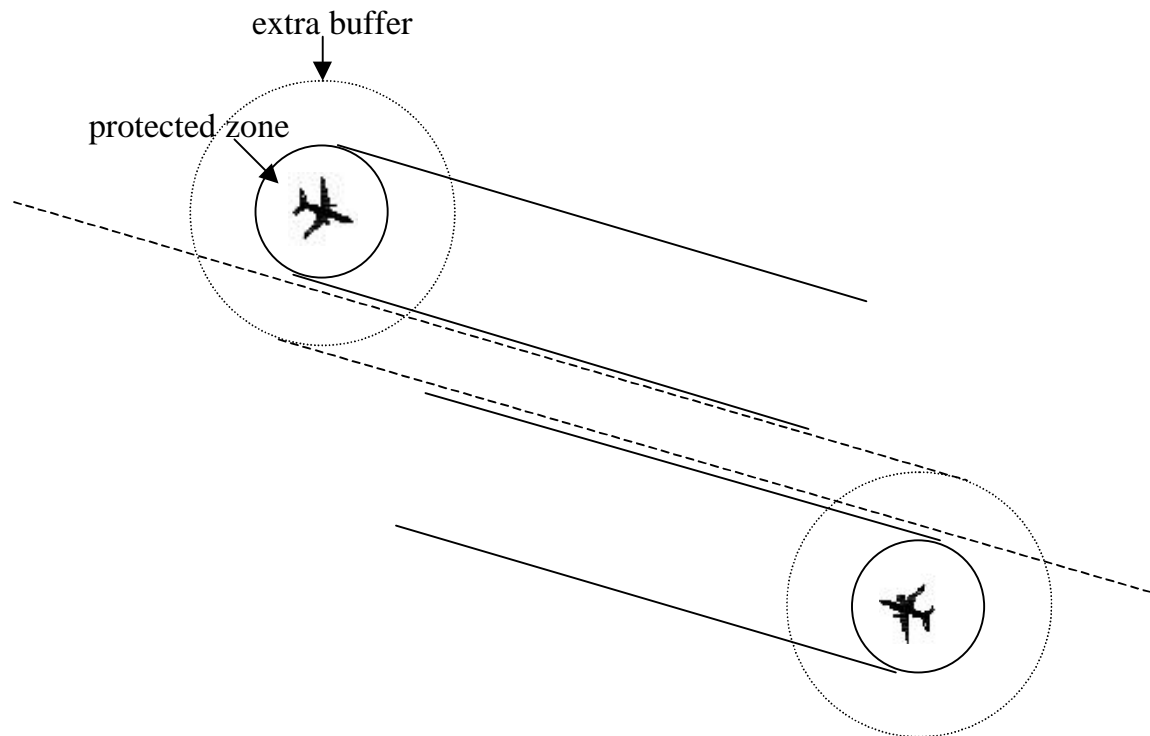
Figure 1. Aircraft Normal Protected Zones and the Effect of Larger Buffer Zones.
(Illustration is not to scale.)

2.2.2 Air Traffic Service Provider (ATSP) Workload Limitations

Currently, the ATSP must provide all separation services necessary for an IFR flight's safety. These tasks include trajectory prediction, conflict detection and resolution, local traffic flow constraint conformance, trajectory adjustments, and flight plan conformance monitoring.

2.2.2.1 Cause of ATSP Workload Limitations

The root cause of ATSP workload limitations is that the ATSP has responsibility for multiple aircraft. Therefore, the ATSP often cannot monitor individual aircraft for long periods of time, and cannot provide individual aircraft the ability to follow user-preferred trajectories. Furthermore, as more aircraft come under the jurisdiction of the ATSP, each aircraft will have less share of the controller's attention. As traffic density increases, the ability to implement user-preferred trajectories decreases.

2.2.2.2 Effect of ATSP Workload Limitations

One effect of ATSP workload limitations is the imposition of larger-than-necessary buffers for protected zones. Because controllers cannot constantly monitor individual aircraft, a buffer is added to the protected zone so that an aircraft is safe until the ATSP has time to revisit the aircraft. These buffer zones have the same effects as the zones caused by trajectory prediction uncertainty described above, and these zones are additive.

Another effect of ATSP workload limitations is a restriction of potential resolution maneuvers that require more monitoring and interaction with the user. The ATSP may select the most easily defined and implemented resolutions, because other, possibly more user-preferred resolutions would require more ATSP monitoring to implement. In the tradeoff of accommodation of user-preferred solutions versus ease of solution implementation, the ATSP must often choose ease of implementation because of workload constraints. In addition, to formulate these in-flight user-preferred resolutions would require more interactions with the user to attain the user preferences. This increased interaction is not possible, since the ATSP also has responsibility for other aircraft.

2.2.3 Lack of User-Preference Knowledge for Resolutions

Flight plans are filed at the beginning of a flight, and often must be changed en route because of conflict situations or adherence to local traffic flow constraints. En-route adjustments to a flight's trajectory are often made without knowledge of user preferences.

2.2.3.1 Cause of Lack of User-Preference Knowledge for Resolutions

The ATSP often must make trajectory adjustments without knowledge of user preferences because no tools facilitate the transfer of this information and the information is difficult to define in a way easily communicated between the flight deck and the ATSP.

2.2.3.2 Effect of Lack of User-Preference Knowledge for Resolutions

The lack of user-preference knowledge means that the ATSP does not take into account this knowledge when creating solutions to traffic problems. Therefore, trajectory changes due to resolution maneuvers may deviate excessively from the user preference, even though a user-preferred resolution exists that solves the traffic problem.

3. Approach

This section first presents an overview of the solution presented by en route free maneuvering to the problems outlined in Section 2. There follows a discussion of how the solution addresses each root source of the problems as described in Section 2. Third is a summary of the benefit mechanisms which motivate research in this concept.

The proposed solutions described below are based upon proposed operational concepts and related research studies.[2,3,4] Their feasibility and potential benefits need to be validated through analysis, simulation and field demonstrations.

3.1 Solution Overview

As stated in the Concept Definition for DAG-TM:

Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local traffic flow management (TFM) constraints.

Free maneuvering aircraft are those that (1) are appropriately equipped, (2) have responsibility for self-separation, and (3) have been granted the authority, capability and procedures needed to execute user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. Free maneuvering aircraft continue to follow defined air traffic rules and procedures as is true of all aircraft.

Free maneuvering will allow aircraft to fly more optimized user-preferred trajectories. Under the CE-5 concept, which takes place in the en route operational domain, flight crews have the authority, tools, and infrastructure necessary to provide their own solutions to traffic conflicts and localized TFM constraints imposed by the ATSP. Such constraints will continue to occur throughout en route airspace; examples are en route metering, miles in trail, and required times of arrival (RTA) in transition.

A user-preferred trajectory modification may be generated by the flight crew, or if time permits it may be created by the AOC and transmitted to the flight crew via datalink. The flight crew instructs the aircraft's flight management system (FMS) to initiate the trajectory, and at the same time on-board automation broadcasts the modified trajectory using automatic dependent surveillance to the ATSP and to other aircraft.

The controller role changes significantly under the CE-5 concept. The controller retains responsibility for all aircraft which are not free maneuvering, called *managed*. The controller uses CD&R decision support tools to maintain separation assurance for managed aircraft, and also to monitor the activities of all aircraft. In the case of a potential conflict between a managed and a free maneuvering aircraft, procedures and flight rules are followed by the free maneuvering aircraft and the controller acting on behalf of the managed aircraft. In order to provide an incentive for aircraft to equip for free maneuvering capability, flight rules include priority status for free maneuvering aircraft in conflicts with managed aircraft.

The traffic management coordinator (TMC) continues to set localized TFM constraints as today. Potential changes in the TMC role are a subject for research.

3.2 Solution Addresses Each Root Problem

The solution of allowing more airborne authority and free maneuvering addresses all of the problems stated in the Problem Description section above.

3.2.1 Free Maneuvering Addresses Trajectory Prediction Uncertainty

One of the causes of trajectory prediction uncertainty is that, once en route, trajectories are viewed in sector-based portions. Under free maneuvering, the flight crew has a trajectory orientation for its own planning and is not restricted by a controller's sector orientation as today. This results in less disruption of the planned trajectory, leading to improved prediction.

Another cause of trajectory prediction uncertainty is the lack of accurate information about the future air traffic environment. Under free maneuvering the flight crew has the information and tools to take a long look ahead on the trajectory toward developing weather and congestion and toward potential conflicts with other aircraft taking into account their intent, and to calculate required maneuvers as early as possible. These activities will reduce uncertainty.

3.2.2 Free Maneuvering Addresses ATSP Workload Limitations

The root cause of ATSP workload limitations affecting user preferences is that the ATSP must take authority for multiple aircraft. Each flight crew of a free maneuvering aircraft has authority for its own trajectory. Therefore, flight crews have the option of following user-preferred routes that were impossible before because the ATSP could not devote enough supervision to a single aircraft.

3.2.3 Free Maneuvering Addresses Lack of User Preference Knowledge for Resolutions

The root cause of lack of user preference knowledge is that the ATSP does not have ready access to the user-preferred knowledge from the flight deck. The free maneuvering aircraft has the ability to respond to many new and unexpected situations during the flight in accordance with preferences.

3.3 Potential Benefit Mechanisms

As part of the concept validation process, benefits will need to be shown. In this section mechanisms for potential benefit are identified, to be proven in the research. If they are proven, benefits of the concept can then be estimated. The following is a list of potential benefit mechanisms from en route free maneuvering, as identified so far:

- An ATM system based on air-ground distributed control better accommodates traffic growth: In today's system, when an aircraft enters an airspace region, more workload is required to accommodate its entry. In the future system, free maneuvering aircraft entering the airspace do not need to be managed by the ATSP.
- Increased user flexibility: The ability to free maneuver increases the number of available and implementable solution options to traffic problems.

- Reduction in excessive and non-preferred deviations: Since free maneuvering users can constantly monitor their own trajectories, these trajectories can be more tailored to user preferences.
- Reduction in buffers: Since a free maneuvering user makes his/her own separation decision by looking down his/her aircraft's trajectory, as opposed to a central controller looking at all the trajectories, buffers can be reduced.
- An ATM system based on air-ground distributed control lowers user costs: Because users are in control of their own trajectories, these trajectories can be more optimized to the user-preferred path. If the user-preferred path is based on flight economics, free maneuvering should lower user operating costs, offsetting capital investment costs.
- Reduced ATSP workload: Because many aircraft will have self-separation capability under free maneuvering, the ATSP can focus more on aircraft that do not have self-separation capability. Therefore, the curve of workload as a function of traffic density will be below that experienced by today's ATC system.
- Increased predictability of RTA conformance: Free maneuvering aircraft have better tools for achieving an RTA, since they can use trajectory orientation to anticipate conflicts well ahead and have a better chance to recalculate conflict-free trajectories that will meet the RTA.
- Increased system safety: Because users need surveillance information for free maneuvering, both users and ATSP have situation awareness. This two-pronged approach provides redundancy in separation assurance.
- Increased global interoperability: Aircraft equipped for free maneuvering can operate in oceanic and international airspace assuming harmonized ATC support.

4. Operational Requirements

The Operational Needs Statements (ONS) which apply to CE-5 are found in the Appendix. These ONS have been created to support the development and ongoing revision of the AATT ATM/OPSCON. CE-5, En Route Free Maneuvering, applies to two different service areas as defined in the AATT ATM/OPSCON. The table lists the ONS addressed by CE-5 first in the Flight Planning service area and then in the Separation Assurance service area.

5. Operational Environment

This section describes the assumptions behind development of the concept description for en route free maneuvering, the current and future conditions under which this concept will be applied, the baseline ATC situation and what changes may have to occur to support this concept, and different environments in which the problem and solution may take different forms. The section has four subsections as follows:
- airspace structure and constraints
- traffic mix and equipage
- CNS infrastructure
- ATM environment

5.1 Airspace Structure and Constraints

En route free maneuvering is designed for domestic en-route airspace, although many aspects of the concept element could apply to low-density terminal departure and arrival domains, as well as oceanic and international airspace. It will need to operate in unconstrained, constrained, and transition airspace. Unconstrained airspace is a situation where free maneuvering aircraft need make no trajectory adjustments away from user-preferred trajectories except for separation assurance. Constrained airspace includes the following kinds of constraints on user trajectories:
- TFM initiatives
  - traffic volume restrictions
  - flow rate assignments
- area hazards
  - weather
  - SUA

Transition airspace is that portion of en-route airspace immediately outside terminal airspace, within which arriving aircraft are conducting significant descents to their arrival routes and departing aircraft are conducting significant climbs to cruise.

The CE-5 concept does not address strategic traffic management and negotiations concerning constrained airspace, which is the subject of CE-7.

It is assumed that a route structure may exist in the CE-5 environment, along with a system of named waypoints. The latter are used for easy communication of locations. However, free maneuvering aircraft are no longer required to follow the routes. These aircraft may also perform cruise climbs and do not need to adhere to cardinal altitude rules.

Research will determine a set of feasible procedures for ATC to direct "managed" aircraft, including the use of cardinal altitudes and fixed route structures. Initially, it is assumed that managed aircraft follow current cardinal altitude standards and fixed route structures.

The concept of "managed only" airspace may be brought into CE-5. In this airspace, aircraft may only operate if they are managed.

5.2 Traffic Mix and Equipage

There are two types of aircraft: free maneuvering and managed. Free maneuvering aircraft have automation enabling situation awareness, self-separation, and trajectory re-planning. These aircraft have the authority to make trajectory changes with the restriction that no new conflicts be created within a defined period of time (e.g., 8 minutes) by their maneuvers. The appropriate time horizon is a subject of research. They must transmit their position and intent to enable conflict detection and resolution by other free maneuvering aircraft and the ATSP.

Free maneuvering aircraft voluntarily equip themselves for self-separation and trajectory re-planning and, by doing so, achieve the benefits while assuming additional responsibilities. These aircraft have the baseline equipage requirements for today's en route airspace. Required additional equipage includes:
- flight management system
- datalink
- interactive, multifunctional cockpit display
- automatic dependent surveillance
- decision support
  - conflict detection and resolution (CD&R)
  - trajectory re-planning
- Traffic Alert and Collision Avoidance System (TCAS)

All types of aircraft (e.g., air carrier, general aviation, corporate and military) may be free maneuvering. The concept allows, but does not require, association with an AOC. Global interoperability will be a design goal for the free maneuvering aircraft capability.

Managed aircraft continue to be controlled by ATC in a manner similar to today. The concept of managed aircraft equipage is still evolving. In addition to the requirements for today's en route airspace, managed aircraft of the future may choose to obtain some of the equipage that will be required for free maneuvering aircraft, in order to achieve benefits such as increased situation awareness and improved data communications.

5.3 CNS Infrastructure

Datalink is the principal addition to today's communications infrastructure. There are two kinds of ground to air datalink: addressed, for specific constraints, and broadcast, for messages of general interest. Addressed datalink messages to free maneuvering aircraft include controller advisories and traffic management directives for the aircraft, such as commitment to an RTA. Broadcast messages include weather and SUA advisories. Air to ground datalink will be used for pilot acknowledgements.

The Global Positioning System (GPS) is certified for en route navigation. For surveillance to operate effectively, a free maneuvering aircraft must know its own state with significant accuracy including its position which is obtained by reading from a GPS receiver. This state (including position and velocity) and the aircraft's intent must be broadcast regularly via automatic dependent surveillance. Requirements for this broadcast are further described in Section 6.

The surveillance broadcast needs to be received by nearby free maneuvering aircraft and also by the ATSP on the ground. This information along with comparable information on managed aircraft is broadcast ground-to-air as traffic information to all free maneuvering aircraft in that region.

5.4 ATM Environment

An advanced decision support system, operating in conjunction with the controller display, is essential for the controller. This will provide a high level of situation awareness, along with a CD&R capability to anticipate conflicts and to implement conflict-free resolutions as required. For the controller to have the most current aircraft intent information as part of decision support, the ATSP automation must have a data fusion capability which includes radar, Host flight plan, and aircraft state and intent information from aircraft broadcast.

The CE-5 concept does not require any change in strategic traffic management, although changes as a result of CE-5 may be beneficial. Further research is needed to demonstrate whether changes in local traffic management, either in automation or procedures or both, are required or beneficial.

6. Operational Characteristics

The discussion of operational characteristics for CE-5, en route free maneuvering, starts with general considerations which include all actors. This is followed by subsections addressing characteristics from the perspective of the ATSP, the pilot, and the AOC respectively.

In order to implement free maneuvering, several system capabilities are necessary. First, information exchange among all actors must be expanded. CE-5 relies on DAG-TM CE-0, Information Access/Exchange for Enhanced Decision Support, to define the required information. For flight deck situation awareness this includes:
- state and intent information about other aircraft
- current and predicted NAS constraint information (delays, flow initiatives, SUA status)
- 4D weather information (winds, temperature, turbulence, storm cells, icing, etc.)
- real-time pilot reports from aircraft maneuvering near weather-impacted areas

This information comes directly from the ground infrastructure or from other aircraft.

Second, new automation is necessary for both the flight deck and ATC. The flight deck needs automation to process the incoming information for situation awareness, and to assist in the creation of valid, optimized trajectories based on that incoming information. ATC automation also needs to be enhanced for situation awareness, including awareness of free maneuvering aircraft.

Third, the roles and responsibilities of flight crews and the ATSP must be established. Currently, trajectory change authority resides only with the ATSP. Under free maneuvering conditions, either the flight crew or the ATSP may have authority, depending on the situation. Also, free maneuvering aircraft must be integrated with managed aircraft. The capability for this meshing of ground and airborne traffic management must be achieved for free maneuvering to be successful.

Concept Element 5 attempts to meet the above requirements by distributing responsibility between flight crews and controllers as a function of time to point of closest approach, as presented in Figure 2.[5] Several temporal zones are defined, based on the concept that user and controller goals, and hence their resolution strategies, change as a function of time to the point of closest approach. The sizes, relative locations, and characteristics of these zones will be subjects of research.

For conflicts detected while in the non-coordinated resolution zone, appropriately equipped aircraft have the opportunity to resolve the conflict without participation by the controller. Aircraft state information, such as position and altitude, and intent information, such as upcoming trajectory-change points, are broadcast from each aircraft. Based on these data as well as knowledge of goals, performance, and the environment, airborne decision support automation provides the crews with specific maneuver advisories. Non-coordinated resolutions are based entirely on the flight management goals of the participants. One aircraft may provide the entire resolution maneuver or several aircraft may maneuver partially. Custom airborne CD&R algorithms may be used, and resolutions take place either by direct negotiation or by each crew observing the actions of the other.
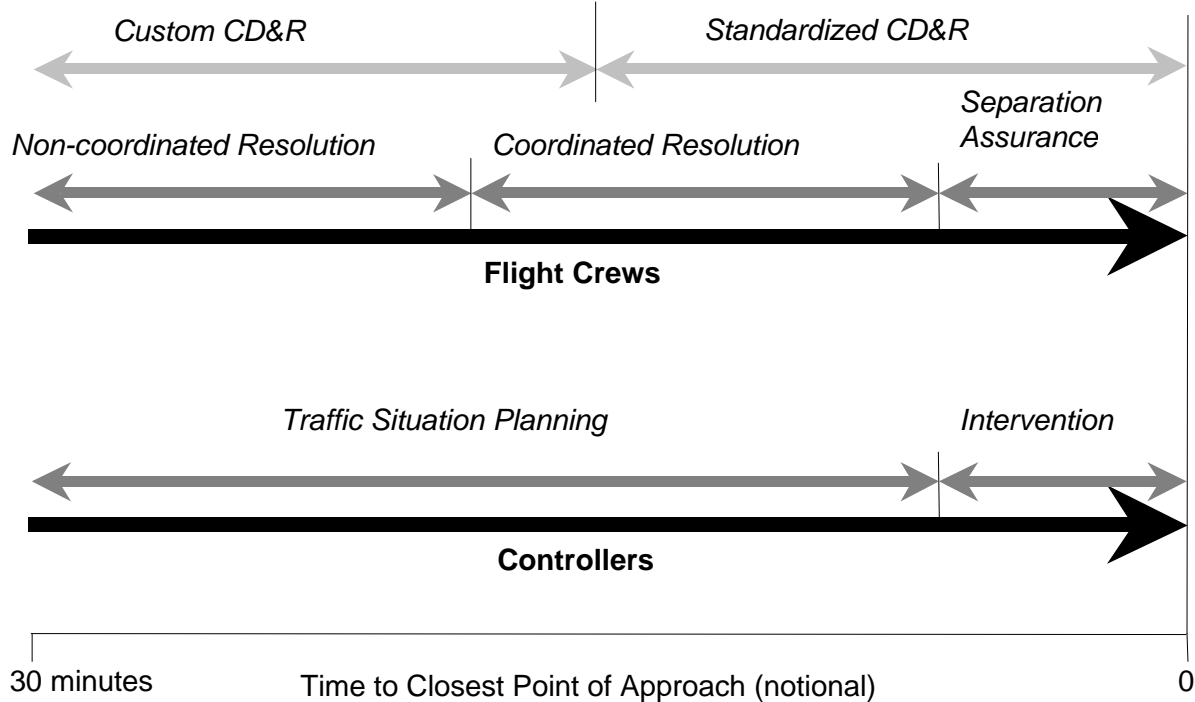
Figure 2. Flight crew and controller temporal zones

Concurrently, controllers are in the traffic situation planning zone and use decision support automation to maintain awareness of the traffic situation. With this awareness, they may predict future regions of traffic complexity too great to enable safe intervention. One measure of traffic complexity may be the number of conflicts predicted to occur in a region. Controller automation provides advisories to reroute some aircraft away from a predicted high-complexity region, or if found necessary for concept feasibility, advises controllers to cancel autonomous maneuvering authority for some or all aircraft.

If flight crews do not resolve the conflict within the time defined by the non-coordinated resolution zone, they enter a coordinated resolution zone. At such a point aircraft are required to follow predetermined rules for resolving a conflict. The rules dictate which aircraft must maneuver and/or the maneuver degrees of freedom. They may be based on extensions of visual flight rules. If the time to separation violation continues to decrease beyond a specified threshold, all aircraft may be required to use identical conflict detection and resolution algorithms. Assuming each flight crew has identical information, the advisories provided to each are compatible. For these situations, crew goals and maneuver efficiency are secondary to safe conflict resolution.

An important goal for airborne separation assurance within the DAG-TM concept of operations is to resolve conflicts before a controller needs to intervene. However, if the aircraft do not achieve a conflict resolution, they will enter the controller's intervention zone. Within the zone, whether the controller has the responsibility to intervene or just the option to intervene will be a subject of research. By intervening, the controller assumes responsibility for separation

14

assurance and exercises positive control. The size of the zone is based on look-ahead practices and comfort levels of controllers. The controller is provided ground-based automation to assist in intervening and resolving the conflict by issuing clearances for one or more aircraft to maneuver. Concept feasibility depends on the intervention zone being a reasonable size.

The flight crew's separation assurance zone corresponds to the controller's intervention zone, as shown in Figure 2. Airborne separation capability should be used to maximize safety in this zone, even though the controller may have responsibility for separation assurance. In the separation assurance zone, crew goals, maneuver efficiency, and passenger comfort are secondary to safe conflict resolution or collision avoidance. To minimize the number of missed alerts, conflict detection may be based on aircraft state information only.

A zone not shown in the diagram is the TCAS zone. We may assume that all free maneuvering aircraft are equipped with TCAS, which provides an independent alert and a resolution advisory to a conflict occurring in less than about 40 seconds.[6]

An initial estimate for the initiation of the coordinated resolution zone is 15 minutes before closest approach; and initiation of the separation assurance/intervention zones, 5 minutes. Research will further explore and validate/adjust these time horizon estimates.

There are a number of assumptions which follow from the distributed responsibility concept. First, controllers' interaction with free maneuvering aircraft normally consists of advisories and traffic management directives, such as the need to meet an RTA or to avoid areas of traffic saturation. Second, a free maneuvering aircraft may make trajectory changes without restriction, with the exception that it shall not make a maneuver which creates a new conflict with any aircraft (free maneuvering or managed) within a defined period of time (e.g., 8 minutes). Third, free maneuvering aircraft need automatic surveillance broadcasts from other free maneuvering aircraft for adequate situation awareness. These broadcasts should include state and intent and occur at a frequency of about 1 per second. Fourth, to complete situation awareness free maneuvering aircraft need to receive traffic information broadcast from the ground which include equivalent data on managed aircraft. These broadcasts may be constrained to every 12 seconds due to the radar update rate. Fifth, surveillance broadcasts need to be received by the ground and integrated into ground automation to provide controllers an equal situation awareness to that of free maneuvering aircraft, with a concurrent CD&R process. The CD&R systems in air and ground are equivalent in capability but are not necessarily built to the same design.

6.1 ATSP View

The principal interfaces between the controller and free maneuvering aircraft are the issuance of traffic management directives, including RTAs, for traffic management purposes; and potential communications within the intervention zone, to be determined by research. The traffic management conditions may exist both in en route cruise and in transition. In developing an RTA, first an ETA is given by the flight crew. Second, a soft RTA is negotiated between ATSP and flight crew at a time X minutes ahead of reaching the fix, where X is currently assumed 30 minutes for research purposes. Third, a frozen RTA is set to which the flight crew must commit.

If a free maneuvering aircraft misses an RTA, the re-planning responsibility is shared. The service provider will find a gap for aircraft re-sequencing, provide a new RTA, and the aircraft will replan its trajectory to meet it.

The controller monitors all aircraft, both managed and free maneuvering, in his or her sector. Monitoring conflicts which do not involve managed aircraft is a secondary workload requirement similar to today's VFR flight following. ATSP automation will monitor whether free maneuvering aircraft are conforming to their broadcast intent and may notify the controller when there are deviations. The controller may issue conflict advisories and path deviation advisories to free maneuvering aircraft, especially in cases of conflicts between managed and free maneuvering aircraft.

6.2 Pilot View

The flight crew of a free maneuvering aircraft has responsibility for the following functions: situation awareness, self-separation assurance, flight re-planning, and adherence to constraints issued by the ATSP. The last function has been discussed above and is not further addressed here. The capabilities described in the following are considered to be minimum requirements for free maneuvering aircraft, subject to further research.

6.2.1 Situation Awareness

The free maneuvering aircraft has an interactive navigation display which shows weather and traffic data to a distance which will be determined as the concept further matures. Traffic needs to be viewed at least 30 minutes ahead for conflict detection, and weather much farther out for aid in long-range CD&R. Weather information would be best viewed on a second display with a greatly expanded range.

Airborne weather information is integrated based on ground information and on-board weather systems. Information is required on winds, turbulence and convective weather. It is expected that gridded 4-D weather and wind products are available. These may start from centralized sources, then become individually tailored for the flight deck depending on the pilot's weather service provider.

In order for a given free maneuvering aircraft to have situation awareness of other free maneuvering aircraft, each must broadcast its state and intent, with the intent preferably as a 4-D trajectory. The required broadcast radius will be determined through research. Initially, 120 nautical miles is assumed. A traffic information broadcast from the ground provides completeness by showing state and intent of all managed aircraft and free maneuvering aircraft beyond the air-to-air broadcast radius. Flight deck automation merges this information to display traffic out to 600 nautical miles from the aircraft.

6.2.2 Self-Separation Assurance

The discussion of self-separation assurance by free maneuvering aircraft is divided into four highly interrelated topics: trajectories, CD&R, flight rules, and issues concerning intent.

Trajectories

To aid in designing separation assurance capabilities, a number of different trajectories are first defined for the purposes of conflict detection and resolution. There are five trajectories for a subject free maneuvering aircraft. These are:
- state-projection trajectory. This is an extrapolation of current position, speed and heading.
- intent trajectories
  - commanded trajectory - the route the aircraft's flight management system (FMS) actually flies given autoflight commands and aircraft performance constraints, and assuming no more pilot inputs.
  - planning trajectory – best prediction of what the aircraft shall do given all "known intent".
  - provisional trajectories – alternative routes tested for hazards using the planning trajectory method.
  - inferred intent trajectory – modification to the planning trajectory when the aircraft is not maneuvering consistent with "known intent".

There are three trajectories for surrounding traffic, called the intruder. These are:
- state-projection trajectory.
- estimated intent trajectory – based on intruder trajectory broadcast if available, and traffic processing functions (ambiguity resolution, data confidence, data fusion).
- inferred intent trajectories – possible trajectories for the intruder when estimated intent fails to produce a deterministic result.

Conflict Detection and Resolution

Each free maneuvering aircraft has a CD&R decision support tool which provides the flight crew a conflict alert with an airspace hazard or intruder traffic well ahead of the conflict. Given trajectory prediction accuracy considerations, it is estimated that reliable alerts could be provided about 30 minutes ahead, to be confirmed by research. One or more resolution trajectories are also provided. The CD&R tool utilizes traffic, winds and area hazards in calculating conflict alerts and conflict-free resolution trajectories. Traffic constraints and RTAs are also used to constrain the resolutions. Conflict alerts and resolutions are shown on the flight deck's interactive navigation display, as an addition to the flight crew's situation awareness.

For conflicts within the standardized CD&R zone or closer, the CD&R tools on different aircraft must use the same algorithm so that if two conflicting aircraft both maneuver, they will move away from each other. For conflicts within the TCAS zone, TCAS will take precedence.

It is a hypothesis that a free maneuvering aircraft can perform adequate trajectory prediction of an intruder to perform CD&R, without having detailed knowledge of the intruder's performance characteristics. This comes into play in transition when most aircraft are performing climbs and descents, and the speeds and altitude change rates differ greatly among different aircraft types.

The initial estimate, to be confirmed by research, is that to fulfill CD&R requirements a free maneuvering aircraft should broadcast its intent forward through the next two trajectory change points (TCPs).

A free maneuvering aircraft should check its entire en route flight plan for airspace conflicts, but only 30 minutes ahead for conflicts with other aircraft due to expected trajectory prediction uncertainties.

Flight Rules

Flight rules provide the means for procedural conflict resolution. They specify for particular conflict situations who has lower priority (i.e., who deviates) and what restrictions exist on maneuvering (i.e., how they deviate).

Simple flight rules that are easily recollected and interpreted are preferred to more complicated rules. The optimal level of complexity is a research question, involving tradeoffs among flexibility of maneuver, predictability of maneuver, and separation assurance.

If a free maneuvering and a managed aircraft are in conflict, the baseline concept gives the free maneuvering the right of way. The free maneuvering aircraft may not, however, create a near-term conflict by changing intent.

Intent

A controller assures separation for managed aircraft in the same way that pilots of free maneuvering aircraft assure separation for themselves. In either case, the responsible party may conduct tactical maneuvers for safety reasons. There will be situations where a free maneuvering aircraft makes tactical moves for safety, thereby having its intent uncertain to the controller. There will be situations where a controller directs a managed aircraft to make tactical moves for safety, thereby having its intent uncertain to nearby free maneuvering aircraft. This is true even though the aircraft's motion will be broadcast in both cases and will be received by the other party. There still are questions – will that aircraft continue on its current heading? It's turning – how far will the turn go before it straightens out? Will it turn back, and when?

Robust decision support systems are available both to the controller and to pilots of free maneuvering aircraft to handle situations of uncertain intent. In addition, the controller may issue an advisory (datalink or voice) to the free maneuvering aircraft in cases of controller action but this is subject to workload.

6.2.3 Flight Re-Planning

The free maneuvering aircraft has the following restrictions on the flight re-planning function. The aircraft must be able to satisfy separation constraints, avoid traffic and area hazards, operate in a 30-minute look-ahead period for aircraft-to-aircraft conflicts, operate within aircraft performance limitations, and satisfy user preferences to the extent possible. It must be able to re-plan to meet RTAs imposed by ATC. It must broadcast new trajectories resulting from new plans. The aircraft is supposed to adhere accurately to its planned trajectory in the absence of disturbances. There may be a penalty for a flight crew not adhering to its broadcast trajectory.

Re-planning may be strategic or tactical. Strategic re-planning is performed by determining a complete solution to one or more problems or constraints, such as hazards or RTAs, prior to executing the solution. Tactical re-planning is performed by selecting and executing a maneuver

to avoid a problem before a complete solution is available, with the understanding that additional maneuvers may be required "on the fly", as the traffic situation develops.

6.3 AOC View

The AOC interaction with the flight deck or the ATSP is not a central part of the CE-5 detailed concept. For air carrier aircraft, the AOC transmits company constraints to the flight deck as a factor in flight planning and re-planning. Given enough time, the pilot may consult with the AOC and request advice on flight plan changes. The AOC may communicate with traffic management for collaborative decisions which will satisfy traffic flow constraints. All of this activity may influence the ATSP and flight crew actions, and is part of the larger DAG concept, but is behind the scenes as far as examining and implementing en route free maneuvering is concerned.

7. NAS Functional Impacts

This section discusses the NAS impacts, including planned NAS architecture components, of the concept as described. Section 7.1 describes functional requirements, and section 7.2 shows the functional design which derives from these requirements.

7.1 Functional Requirements

The following functional changes from the current NAS, expressed in terms of technology and infrastructure, are needed to support the concept. These are described in the areas of Communications, Navigation, Surveillance, Automation, Weather and Traffic Management.

7.1.1 Communications

CE-5 relies on DAG-TM CE-0, Information Access/Exchange for Enhanced Decision Support, to define required communications. These include the following. Ground-to-air communications with free maneuvering aircraft are both by datalink and voice. Datalink communications are both broadcast and addressed. The ATSP broadcasts advisories on SUAs, congested areas, flow constraints and weather, and provides detailed traffic information to be utilized by the flight deck's decision support tools. Aircraft-specific advisories and flow constraints such as RTAs are sent by addressed datalink. Voice communication may be used for this latter function but on an exception basis.

Weather service providers send winds and weather, probably as gridded products, via addressed datalink. These products are tailored to the aircraft position and user planning requirements. AOC-flight deck communication is facilitated by use of company addressed datalink.

Air-to-ground communications from free maneuvering aircraft are by addressed datalink and voice. Addressed messages include negotiations concerning flow constraints, message received, and accept/reject action. Voice communication may be used for these purposes but by exception.

Air-to-air addressed communications between free maneuvering aircraft may occur during aircraft-aircraft conflicts in the non-coordinated resolution zone. In addition, free maneuvering aircraft issue surveillance broadcasts, discussed in 7.1.3.

There is no change in managed aircraft communications except that if the managed aircraft has datalink, controllers may send directives via addressed datalink. The air-ground messages would include message received, and accept/reject.

7.1.2 Navigation

There are no new functional navigation requirements imposed on the service provider by the CE-5 concept. The GPS is assumed certified as a means of navigation and is relied on as part of the aircraft's state information and to check its trajectory adherence accuracy.

The free maneuvering aircraft must have an advanced flight management system (FMS) capable of adhering to a planned 4D (i.e., position, altitude, and time) trajectory to a specified Required Navigation Performance (RNP) level, to be determined by research.

7.1.3 Surveillance

Free maneuvering aircraft must broadcast information for surveillance purposes based on the aircraft's trajectory data calculated by its FMS. It broadcasts state and intent data, with state data at 1 second intervals and intent data every nth broadcast, where the value of n is a research question. How much information is required in the intent messages, namely level of detail and time period, will be determined by research. The initial assumption is two trajectory change points, or enough TCP's to cover 30 minutes, whichever is greater.

The service provider must receive these broadcasts from free maneuvering aircraft and perform data fusion with radar surveillance information and Host flight plan data. This process creates a comprehensive picture of traffic state and intent including both free maneuvering and managed aircraft. This traffic information is broadcast for reception by free maneuvering aircraft to provide them with about a 600 mile (30 minute) traffic situation awareness.

7.1.4 Automation

Free maneuvering aircraft must have the following automation capabilities:
- collect and process intruder aircraft data
- collect and process area hazard data
- develop knowledge of state and intent of itself and intruder traffic
- perform CD&R, meeting multiple simultaneous airspace and traffic management constraints
- perform trajectory re-planning
- accept user preferences
- provide interactive navigation display for flight crew situation awareness and alerting
- prioritize constraints, including managing over-determined situations, namely where there is no conflict resolution which satisfies all constraints

The service provider needs to develop an increased surveillance data fusion capability as described above for the purpose of providing the controller with a good decision support capability. Specific requirements for controller decision support and displays for the CE-5 concept need to be further developed.

7.1.5 Weather

Improved wind and weather models and information distribution are needed for free maneuvering aircraft to accurately plan and fly their trajectories. Accurate winds are needed for proper functioning of the CD&R routines.

The same scope and detail of weather information is available to the ATSP as to the free maneuvering flight crews. It is important that the data set be common to all users and the ATSP, so that during coordinated conflict resolution the different actors will perform as expected.

7.1.6 Traffic Management

There are no changes required for national traffic management, that is at the Command Center level. The CE-5 concept can utilize traffic management directives in whatever form they may take. However, improvement in collaboration between the TMC and the flight crew, and use of

the 4D flight object, would enable real-time user preferences to be incorporated into traffic management constraints.

7.2 Functional Design

Figure 3 is a functional design diagram showing those NAS systems and services which are essential for supporting the CE-5 concept. Current and future air traffic systems and services which are general to air traffic control but not specifically utilized in CE-5 are not shown.
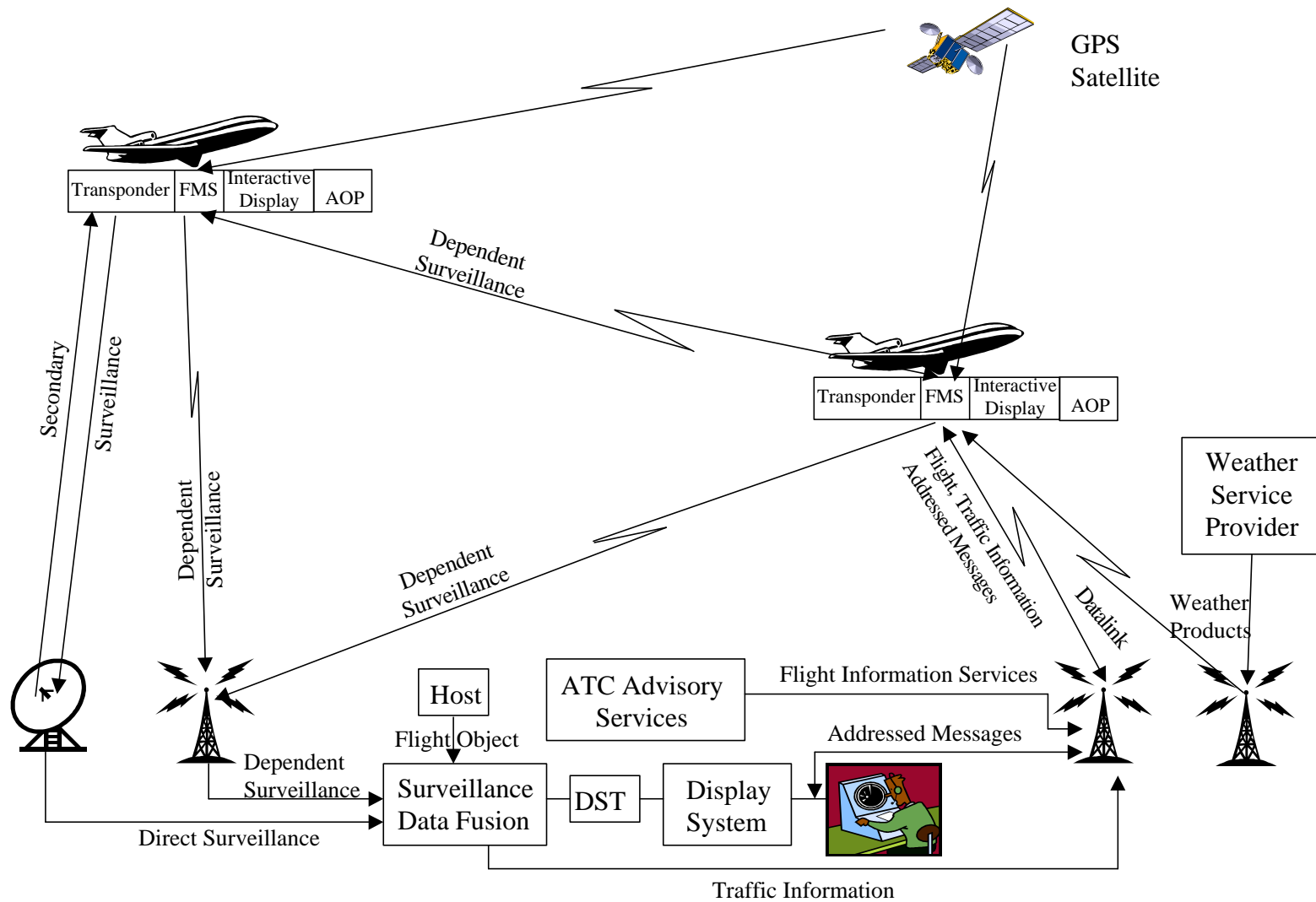
The two aircraft shown are free maneuvering. Each maintains accurate position information and trajectory conformance using GPS as an input to the flight management system (FMS). Each free maneuvering aircraft broadcasts surveillance information to other free maneuvering aircraft and to a ground receiver which transmits this to ATC automation. The ATSP makes use of secondary (beacon) surveillance which determines position, altitude and other information from both free maneuvering and managed aircraft.

Within each en route center, dependent and direct surveillance information are combined with flight object information from the Host in a data fusion routine, presenting accurate information to each sector controller on all flights. A decision support tool supplements this with essential CD&R information.

Traffic information from the data fusion process is broadcast via datalink for use by free maneuvering aircraft, to provide a complete situation awareness of intruder traffic including both free maneuvering and managed. Two additional broadcasts add to the free maneuvering aircraft's situation awareness. One is the ATSP's flight information services including traffic management advisories and SUA status. The other is a gridded array of aviation weather and winds from a weather service provider, which in turn is based on FAA, NOAA and private data sources. Each weather service provider may furnish weather products tailored to its subscribers.

In addition to the FMS, the free maneuvering aircraft automation includes an interactive display and the AOP, which furnishes the pilot with essential decision support concerning CD&R and trajectory planning.

The controller and pilot exchange addressed messages via datalink. These messages include advisories and traffic management directives, as discussed previously.

GPS
Satellite

Transponder | FMS | Interactive Display | AOP

Dependent
Surveillance

Secondary
Surveillance

Dependent
Surveillance

Dependent
Surveillance

Transponder | FMS | Interactive Display | AOP

Weather
Service
Provider

Flight, Traffic Information
Addressed Messages

Datalink

Weather
Products

Dependent
Surveillance

Host

Flight Object

ATC Advisory
Services

Flight Information Services

Addressed Messages

Dependent
Surveillance

Surveillance
Data Fusion

DST

Display
System

Direct Surveillance

Traffic Information

Figure 3. CE-5 Functional Design Diagram

23

8. User/Operator Roles and Responsibilities

In this section the focus is on the roles and responsibilities of each of the active participants in the CE-5 concept. Subsections address the roles and responsibilities of the ATSP, the pilot, and the AOC respectively.

8.1 ATSP Roles and Responsibilities

The air traffic controller directs managed aircraft in a similar manner as today, while monitoring the activities of free maneuvering aircraft. The controller continues to send the following four types of messages to aircraft, but only two of these apply to free maneuvering aircraft:

- Clearance. This is a required maneuver for separation, e.g. move to new altitude, new heading. The clearance applies only to managed aircraft.
- ATC instruction. Similar to a clearance but more urgent, e.g. "go around", "turn left to [new heading]". Again applies only to managed aircraft.
- Advisory. Provides a flight crew with awareness of traffic, weather, turbulence, etc. To all aircraft.
- Traffic management directive. Informs flight crew of restricted airspace or RTA assignment. To all free maneuvering aircraft and those managed aircraft capable of meeting an RTA.

Under some circumstances, a free maneuvering aircraft will become managed. This occurs only with controller and flight crew consent. It is a design goal of the concept that this transfer of responsibility authority should be smooth and predictable. The conditions under which such a transfer may occur will be determined by research.

8.2 Pilot Roles and Responsibilities

As discussed previously, the free maneuvering aircraft pilot has responsibility for situation awareness, separation assurance, flight re-planning and execution, and adherence to constraints issued by the ATSP.

The pilot has a CD&R system that provides predicted conflict alerts and resolution maneuver options. Resolutions may be strategic or tactical. Strategic resolution is performed by determining a complete solution to one or more conflicts, which may be constrained by RTAs or other factors, prior to executing the solution. Tactical resolution is performed by selecting and executing a maneuver to avoid a conflict before a complete solution is available, or even without ever looking for a complete solution, with the understanding that additional maneuvers may be required.

A free maneuvering aircraft may request information from a controller. Such a request is addressed by the ATSP on a time-available basis similar to the interaction with today's VFR traffic. In addition, a free maneuvering aircraft may request change of status to managed. This status change must be accepted by the controller before it takes effect.

8.3 AOC Roles and Responsibilities

CE-5 does not have significant effects on AOC roles and responsibilities.

9. Operational Modes and Scenarios

This section discusses and illustrates the modes in which the CE-5 concept, En Route Free Maneuvering, has to operate in order to be successful. This discussion is oriented to the full concept. Additional modes may be necessary during transition to the achievement of the full concept.

The section divides the discussion into three sub-sections addressing normal or nominal modes, off-nominal modes, and failure modes.

9.1 Normal or Nominal Modes

Normal or nominal modes are conditions which en route free maneuvering is expected to encounter regularly and within which the concept will work in a routine manner. The following is a classification of these modes:

1. En route outside transition airspace
- Unconstrained, with the exception of aircraft/aircraft conflicts
- Constrained
  - Traffic management
    - Excess density/complexity areas to be avoided
    - RTA as a flow management mechanism
  - Weather – slow-moving, tactically avoidable fronts
  - SUA scheduled activation/deactivation

Figure 4 illustrates en route, outside transition modes as a top view. The left-hand illustration shows unconstrained airspace which will have a certain number of aircraft-aircraft conflicts. The right-hand illustration shows various conditions of constrained airspace. Note the use of the RTA to manage flow through a constricted corridor. Of course in the CE-5 concept many aircraft will be able to avoid such corridors through adequate flight planning, but others may not be able to because of changing conditions, or will choose to take the corridor because the delay is less than that created by a diversion.

2. En route transition airspace
- Unconstrained, with the exception of aircraft/aircraft conflicts
- Constrained
  - Traffic management
    - Excess density/complexity
    - RTA
  - Weather
  - SUA scheduled activation/deactivation

Figure 5 illustrates en route transition modes as a profile view. The left-hand illustration shows unconstrained airspace within which climbing, descending and overflying aircraft are operating near a TRACON boundary. Many types of aircraft-aircraft conflicts must be protected against, including overflights which conflict with climbing or descending aircraft which are leaving or approaching the TRACON, and aircraft with different performance characteristics descending

toward the same fix. The right-hand illustration shows constrained operations with similar kinds of constraints as discussed previously. In transition airspace the RTA is an instrument for efficient merging and sequencing in preparation for the approach and landing procedures within the TRACON. Aircraft in the transition zone, as contrasted with operations outside transition, have to react to constraining situations more quickly and possibly replan more frequently.

Both mode classes described above (items 1 and 2) apply to mixed equipage traffic, that is free maneuvering aircraft integrated in airspace with managed aircraft.

9.2 Off-Nominal Modes

Off-nominal modes are defined as operation in conditions which stress the applicability of the concept. In general these are conditions in which anything changes quickly and/or unexpectedly. Examples are the following:

- Weather
  - Large fronts which developed unexpectedly
  - Fast moving fronts
- SUA unscheduled activation on short notice
- Traffic complexity developing quickly and not anticipated by traffic management
- An unusual increase in traffic volume

9.3 Failure Modes

Failure modes are modes which can apply to each of the nominal or off-nominal modes defined above. A failure mode is a condition which results in the aviation/ATC system becoming degraded. Performance may be locally substandard during a failure mode, and success is defined as the ability to move to a safe condition.

The following is a classification of failure modes and a description of failures which may occur within each class.

Airborne automation failures (free maneuvering aircraft)

- GPS signal receipt or processing failure
- dependent surveillance failures
  - receiver
  - transmitter
- dependent surveillance transmission errors
  - lacks intent or performance information
  - sends wrong intent information
- Datalink failures
  - receive ground-air datalink
  - transmit air-ground datalink
- Conflict detection failures
  - false conflict alert
  - missed conflict
- Conflict resolution fails to find resolution
- Display failures

- Navigation errors (e.g. autopilot failure)
- Entire airborne automation failure

Ground automation failures
- Conflict detection failures
  - false conflict alert
  - missed conflict
- Conflict resolution fails to find resolution
- Display failures
- Entire ground decision support tool failure

CNS infrastructure failures or degradation
- Flight advisories failure
  - no weather advisories
  - no airspace advisories
- Traffic information failure
- Addressed ground-air/air-ground datalink failure
- Radar failure

Pilot errors (free maneuvering aircraft)
- Error in setting autopilot so that aircraft flies off pilot's intended course
- Pilot changes flight plan without filing change
- Pilot flies off broadcast planning trajectory
- Pilot vectors to create conflict
- Pilot fails to resolve detected conflict
- Failure to follow flight rules

ATSP errors
- Controller vectors managed aircraft to cause conflict with free maneuvering
- Controller fails to transmit TM directives to free maneuvering aircraft
  - airspace avoidance
    - weather front
    - saturated sector
  - revised RTA

Unconstrained   **Constrained**
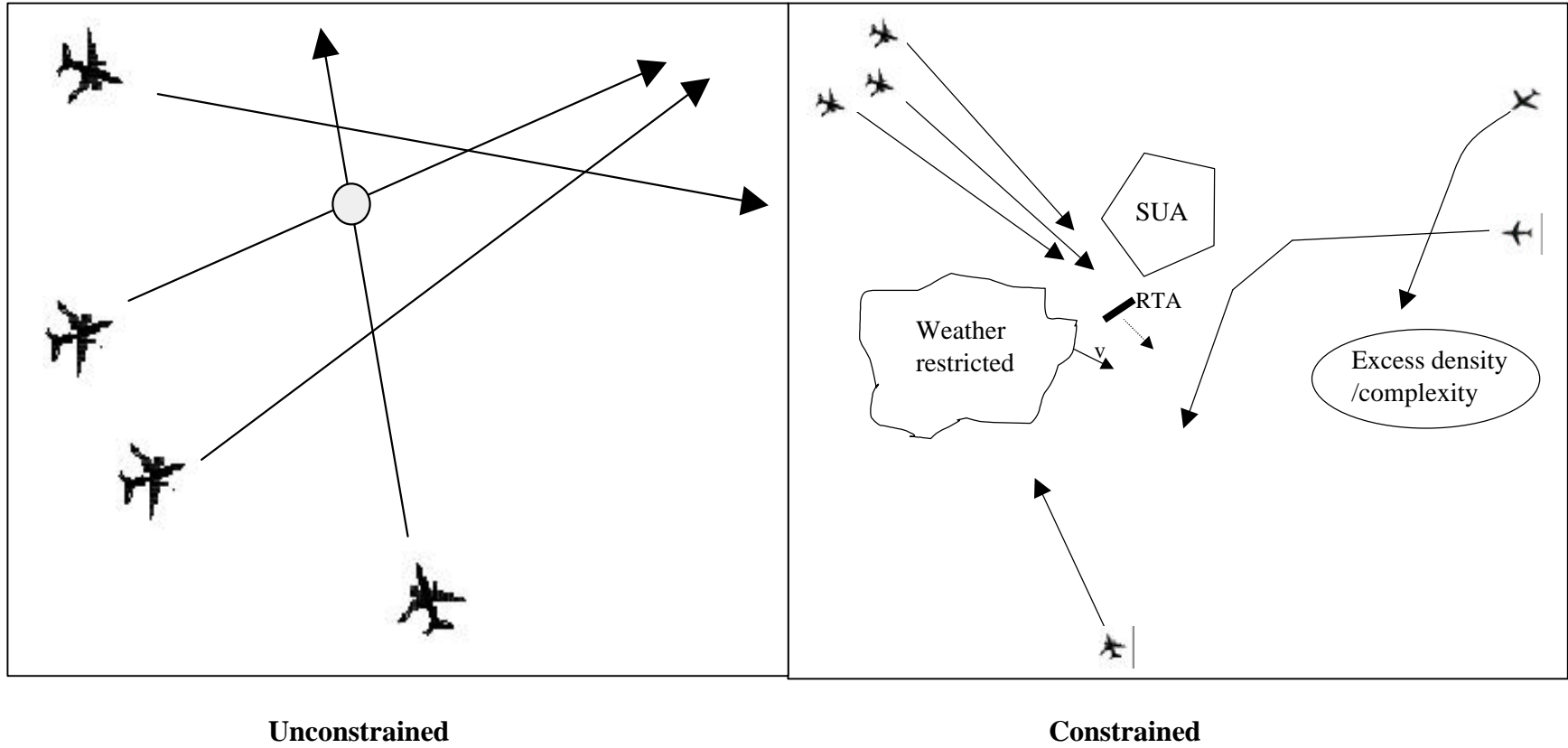
Figure 4. En Route Operational Modes Outside Transition (Top View)

Excess density /complexity

RTA

SUA (Behind)

Weather (restricted)

v

TRACON

TRACON
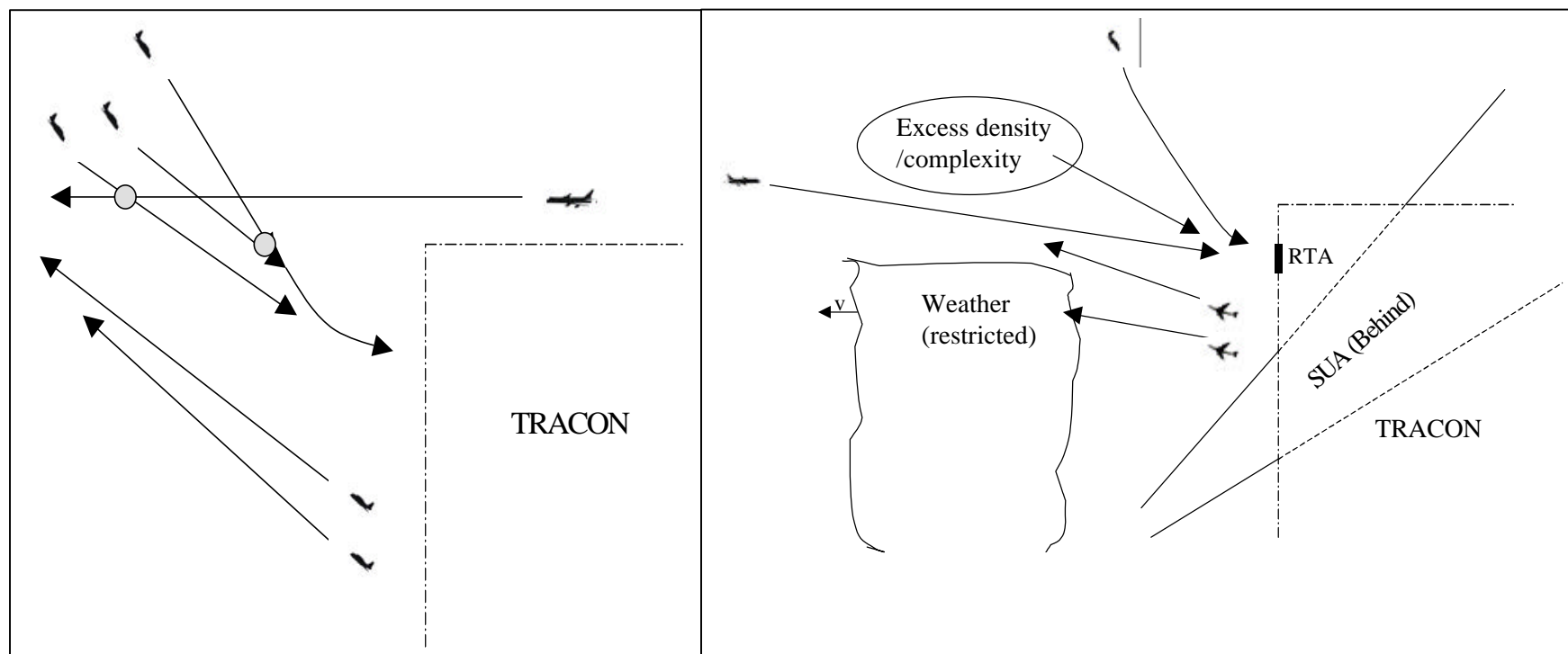
Unconstrained

Constrained

Figure 5. En Route Operational Modes In Transition (Profile View)

10. Operational Process/Operational Sequence Diagrams

This section describes and diagram at a high level, the processes to be followed during the solution created by the concept. The processes are based on the description of roles and responsibilities (Section 8) and operational modes (Section 9).

The following major operational processes have been identified:
- Flight Crew
  - User-Preferred Flight Plan/Trajectory Change
  - Traffic Conflicts
  - Area Hazard Conflicts
  - Meet RTA
- ATSP
  - Traffic Conflicts
  - Monitor Free maneuvering Aircraft and Issue Advisories
  - Issue Traffic Management Directives
- Flight Crew/ATSP: Transition of Aircraft Between Free Maneuvering and Managed States

Two of these are discussed below as examples, these are User-Preferred Flight Plan/Trajectory Change and Area Hazard Conflicts. In the discussion, an aircraft is assumed free maneuvering unless otherwise indicated.

Flight Crew: User-Preferred Flight Plan/Trajectory Change

Figure 6 shows the operational sequence diagram for this process. Changing conditions lead the flight crew to question whether the current flight plan/trajectory remains satisfactory. The flight crew evaluates this with the aid of a decision support tool, taking into account user preferences and NAS state information such as traffic management, weather, winds and pilot reports. If the current flight plan/trajectory is still deemed satisfactory in the sense that there is not sufficient benefit to changing it, the process ends. Otherwise, alternative trial trajectories are created by the decision support tool, with reliance on NAS state information.

The flight crew evaluates these alternatives taking into account user preferences. As a result of this evaluation, the flight crew may not see any alternative that is sufficiently better than the current one, and the process ends. Otherwise they choose the best alternative. The flight plan of record for this flight may or may not be changed by this alternative. This depends on the flight plan detail and the extent of the changed trajectory. If it would be altered, the flight crew files a flight plan amendment with the ATSP, then activates the new trajectory. Otherwise, the flight crew proceeds immediately to activate the new trajectory. Note that the new trajectory will diverge at some point from the current trajectory. The divergence may be immediate, or it may not occur until some considerable time into the future. The aircraft's automatic surveillance broadcasts will quickly inform other aircraft and the ATSP of the new trajectory.

Flight Crew: Area Hazard Conflicts

Figure 7 shows the operational sequence diagram for this process. The aircraft's CD&R decision support tool periodically or continuously checks the aircraft's trajectory for area hazards such as weather fronts or active SUAs, using the most current NAS state information. If a hazard is

detected, the decision support tool generates alternative trial trajectories which will be conflict-free. The flight crew evaluates these with the aid of the tool and taking account of user preferences. Out of these alternatives the flight crew chooses the one that is best in their judgment.

As in the previous case, the new trajectory may or may not be so different from the current one that a flight plan amendment needs to be filed. In either case, the flight crew activates the new trajectory and this is quickly broadcast to other aircraft and to the ATSP.
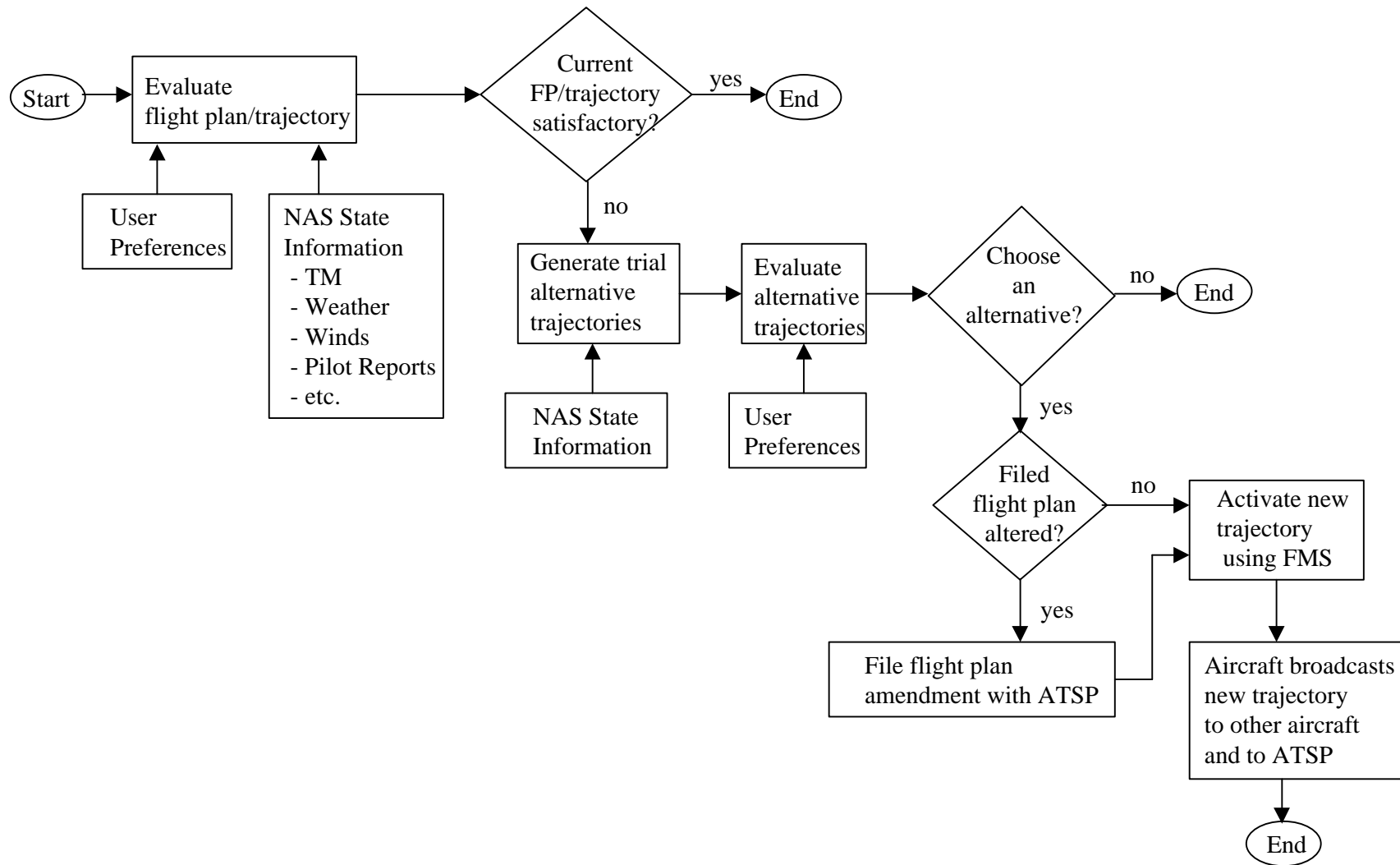
Figure 6. Operational Sequence Diagram for Flight Crew: Flight Plan/Trajectory Change
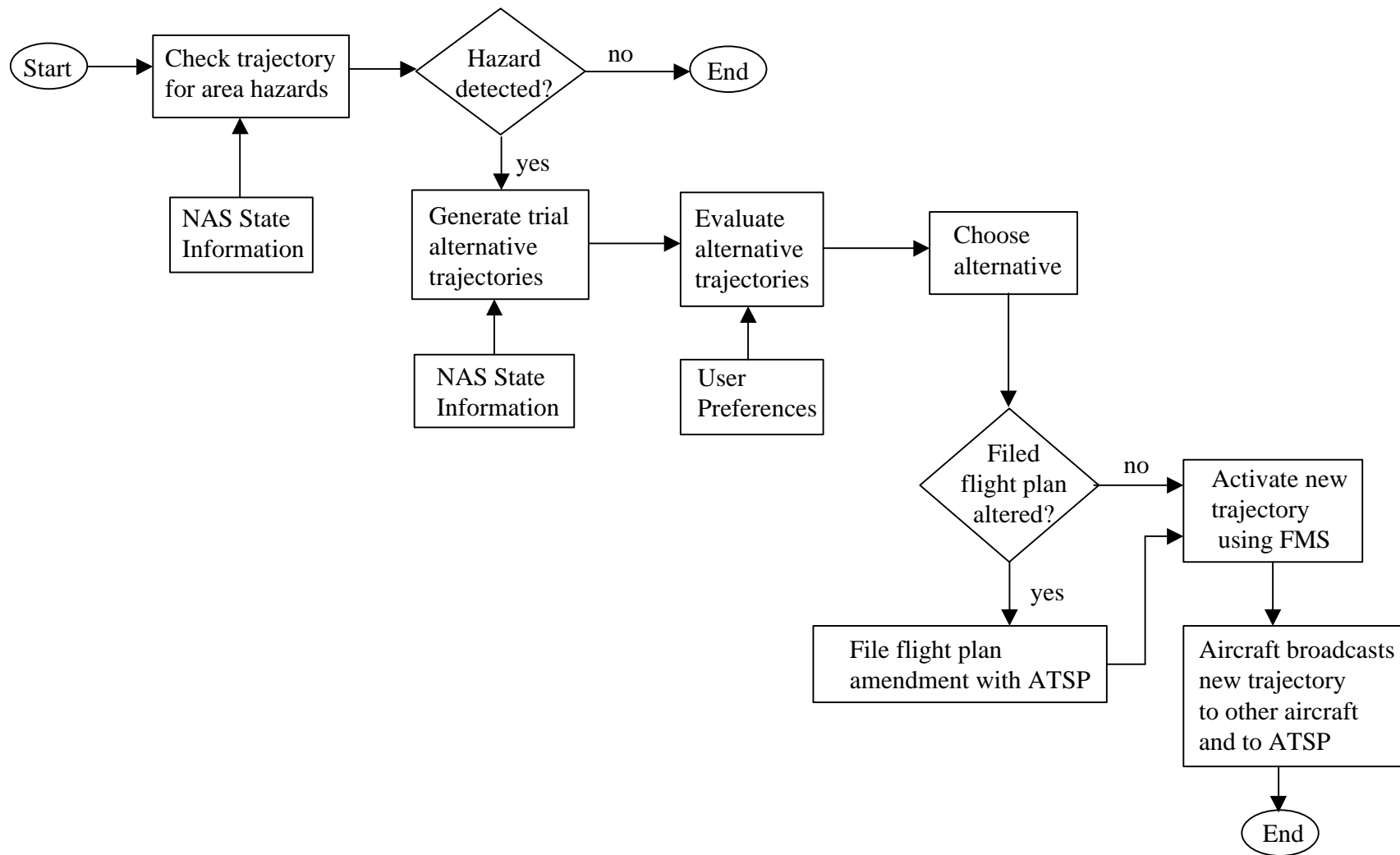
Figure 7. Operational Sequence Diagram for Flight Crew: Area Hazard Conflicts

11. Benefits

The benefit mechanisms described in section 3.3 above, along with other potential benefits, are discussed here in the context of the metrics associated with AATT goals.[7] Key CE-5 potential benefits are summarized in the following paragraphs.

Capacity

The following capacity-related potential benefits have been identified.
- In today's system, controller workload is a strong function of traffic volume since every aircraft is managed. Under free maneuvering, free maneuvering aircraft do not need to be managed by the ATSP and therefore controller workload is a much weaker function of traffic volume. Thus traffic volume could be permitted to increase more with the same level of controller resources.
- An increased volume of airspace can be utilized by free maneuvering aircraft not following a fixed route structure. This is accomplished by many of these aircraft fanning out on routes parallel to heavily used routes, which they will choose to do to avoid congestion.
- Since free maneuvering aircraft have increased situation awareness, separation buffers used by controllers today can be reduced for these aircraft, increasing operational densities in some situations.
- Close trajectory management by free maneuvering aircraft flight crews allows increased RTA conformance, which leads to increased transition airspace throughput.

Flexibility

The following flexibility-related potential benefits have been identified.
- User preferences for free maneuvering aircraft are implemented directly by the user without ATSP approval.
- The ability to free maneuver increases the flight crew's ability to follow user preferences, and their range of solution options to traffic problems.
- The lack of route structure and ability to use the entire airspace allows increased flight plan options for free maneuvering aircraft.
- Operators of fleets of free maneuvering aircraft have greater business flexibility in managing their fleets.

Efficiency

The following efficiency-related potential benefits have been identified. These are separated into benefits to users and to the service provider.
- Users
  - Free maneuvering users should experience reduced operating costs (time and fuel) and reduced delays, due to
    - Increased predictability of operations
    - capability for optimized routing
    - reduced excess spacing buffers
    - reduced excessive resolution maneuvers
  - There will be reduced voice communications for free maneuvering users.

- As the percentage of free maneuvering aircraft increases, managed aircraft should experience reduced delays, since they are a subset of the total traffic and the free maneuvering aircraft are effectively increasing capacity.
- Service Provider
  - The service provider has CD&R and related decision support for ATC clearance advisories.
  - The service provider has reduced voice communications since there is little voice contact with free maneuvering aircraft.
  - Because many aircraft will have self-separation capability under free maneuvering, the ATSP can focus more on aircraft that do not have self-separation capability. Therefore, the curve of workload as a function of traffic density will be below that experienced by today's ATC system.
  - ATSP can focus on traffic management and less on traffic control.

Global Interoperability

The following potential benefits relating to global interoperability have been identified.
- Assuming harmonized ATC systems in the world, free maneuvering aircraft have reduced equipage and training costs for international operations.
- Free maneuvering aircraft have some capability for situation awareness and trajectory re-planning throughout the world, even if no harmonization exists or ground facilities are lacking.

Scalability

The following scalability-related potential benefits have been identified. Scalability refers to the capability of the air traffic system to continue to operate successfully with continually increasing traffic volumes. Scalability has two aspects, operational and economic.
- Operational scalability:
  - Each additional free maneuvering aircraft contributes its own surveillance infrastructure and provides its own separation assurance. This system accommodates growth better than a centralized system which may have limits in capacity to handle traffic growth.
  - Whereas the current paradigm of centralized human planner/controller does not scale with large traffic growth, a distributed system consisting of free maneuvering aircraft growing with the traffic along with ground controllers, is readily scalable.
- Economic scalability:
  - Capital and recurring costs of infrastructure and operations for a single service provider are reduced.

Predictability

The following predictability-related potential benefits have been identified.
- Free maneuvering aircraft are broadcasting their intent. When intent changes, the new intent is broadcast, and maintains predictability of that aircraft for other aircraft and the ATSP.
- A trajectory orientation enables free maneuvering aircraft flight crews to improve trajectory predictability.
- Increased trajectory adherence increases the predictability of RTA conformance, which in turn increases the predictability of arrival traffic.

Access

The following access-related potential benefits have been identified. Access refers to the ability of users to obtain access to airport, airspace, and ATC services.

- Integrated mixed-equipage operations maintains access to all airspace as contrasted with segregated airspace concepts (e.g. European).
- En route free maneuvering enables more frequent use of off-route regions.

Environment

The following environmental potential benefit has been identified.

- More efficient trajectories means less fuel is burned per flight, providing improved environmental benefits.

Safety Impacts

A potential safety improvement is the following. Both free maneuvering aircraft and the ATSP have situation awareness concerning potential conflicts. This redundancy reduces the probability of separation assurance failure.

12. Issues and Key Decisions

The following lists some of the issues that were identified concerning the CE-5 concept. The list is taken from the DAG TM Research Plan, Appendix B-1[8].

"Operations" categories

Separation assurance while adhering to RTA
- Determine separation buffers required to compensate for system inaccuracies and pilot/controller response delays.
- Determine feasibility of optimal descents, optimal climbs, RVSM, RHSM, and cruise climb while in free maneuvering mode.
- For low traffic complexity terminal airspace and simple runway configurations, determine feasibility of free maneuvering for merge at final approach fix.
- What lateral and longitudinal separation standards are enabled by airborne separation assurance?
- How often, or to what extent, can an aircraft deviate for separation assurance and still meet the assigned RTA?
- Determine path stretch limits while meeting RTA.
- Determine ability to meet RTAs while in free maneuvering.

Mixed-equipage integration and segregation
- Can lesser-equipped aircraft be integrated in same airspace as fully equipped aircraft?
- Determine need for route structure, possibly to handle basic-equipage aircraft.
- Determine need for segregation of basic-equipage aircraft in highly complex traffic environments.
- What are the advantages and disadvantages of 1) ATSP providing intent of non-equipped aircraft to equipped aircraft vs. 2) ATSP control of both aircraft?
- How does the ATSP integrate lesser-equipped aircraft that have an RTA constraint with equipped aircraft operating independently without a frozen RTA constraint?
- How will arrival sequencing and spacing be handled for lesser-equipped aircraft in a mixed equipage environment?

Time horizons
- What time horizons (before conflict) need to be established to adequately define varying responsibility and/or authority in DAG-TM as the time-of-conflict approaches?
- What criteria for ATSP intervention balances the flexibility for the aircraft to resolve the conflict (i.e. not too soon) with adequate opportunity for the ATSP to implement a resolution (i.e. not too late)?
- For what conditions and for what time horizons (before conflict) should resolutions be based on 1) flight crew goals and preferences, 2) procedures such as flight rules, and 3) implicit shared algorithms for separation assurance?
- Is a time horizon (before conflict) needed when explicit coordination between aircraft for conflict resolution needs to be superceded by implicit coordination (for example, by using compatible algorithms that ensure coordination)?
- Determine the required sizes and characteristics of the alert zone.

- What is the optimal RTA freeze horizon?
- Determine need for and characteristics of RTA freeze horizon.
- What minimum advance notice is necessary for the flight crew to effectively plan a route around new airspace constraints?
- What minimum advance notice of new constraints is necessary for the flight crew to effectively plan a route that accommodates user preferences?
- Can NAS information be updated often enough to allow flight crews to effectively plan and implement changes in real time?

Intent transfer & inference

- Determine the need to infer intent of other aircraft due to 1) incomplete transfer of information (especially for basic equipage), and 2) situations in which aircraft do not adhere to their broadcast intent.
- What level of dynamic density is the upper limit for viability of airborne separation assurance with intruder intent knowledge?

Traffic situation complexity

- What is the maximum level of traffic complexity at which self-separation is feasible and safe?
- What level of dynamic density is the upper limit for viability of DAG-TM operations?
- How will separation between multiple cruise-climb aircraft be assured?
- Identify airspace constraints, traffic constraints, and weather constraints for which the concept is not feasible.
- Can a level of traffic complexity be reached where free maneuvering can no longer be safely maintained?

Flight rules

- Are priority and maneuver rules (I.e. "flight rules") necessary to manage equitable and reliable conflict resolution under any circumstances?
- What degree, if any, of maneuver freeze horizon is needed to ensure aircraft in proximity do not create a near-term conflict?
- Explore need for and benefits of extended or electronic flight rules. Flight rules types include 1) right-of-way priority rules, 2) maneuver rules, aircraft class rules, and equipment type rules.
- Will trajectory restrictions be required for an aircraft when in proximity to other aircraft? Options include 1) a no-go zone and 2) a maneuver freeze horizon.
- What level of dynamic density is the upper limit for viability of airborne separation assurance with flight rules?
- What is the impact of flight-rules complexity on effectiveness in an airborne self-separation environment?

Environmental predictions

- Define enabling technology required for feasibility, including communications technology, advanced winds prediction technology, advanced dependent surveillance technology, and decision support automation technology.
- How much compatibility is required between ATSP and FD wind and weather information?

- Can flight replanning be robust to changes to wind and weather conditions?
- CNS infrastructure & aircraft capability limitations
- What minimum FD capability and equipage is required for an aircraft to operate in autonomous free maneuvering mode?
- What are the minimum operating CNS infrastructure requirements to permit aircraft to operate in autonomous free-maneuvering mode?
- What tolerances on trajectory adherence are required for self-separation?
- Determine feasibility of airborne self-separation as a function of differing aircraft performance (speed differences, ascent/descent performance differences, equipage differences).
- Determine aircraft trajectory adherence requirements while in climbs and descents or in the face of incorrect winds-aloft predictions.
- How precisely does the aircraft need to meet RTA in time and position?

Equitability, access, stability
- Are flight rules required to ensure that aircraft equipped for self-separation are not always the one to maneuver in a conflict and therefore receive benefit from equipping?
- To what extent can an aircraft with free maneuvering authority limit the maneuver options of other aircraft without negotiation?
- Identify restrictions that may need to be designed to ensure airspace access to all user and equipage classes, to ensure system stability, and potentially to achieve desired capacity.
- Are user penalties required to ensure benefit is received for equipage?
- Determine whether artificial conflict resolution constraints are needed to ensure independent flight decks are not penalized for equipping, and determine what types of constraints would be needed.
- How is equitable resequencing of arrival streams handled when aircraft miss their assigned RTA due to deviating for separation assurance?

Negotiation
- Is direct negotiation between 2 self-separating aircraft in conflict with each other necessary to ensure equitable resolution?
- What level of dynamic density is the upper limit for viability of airborne separation assurance with direct negotiation?

<div align="center">

"Human Factors" categories

</div>

Roles & responsibilities
- Can flight crews retain responsibility for separation assurance without the option to abdicate to ATSP under any circumstance, unless initiated by ATSP?
- Under what conditions, such as predicted future traffic loading or predicted loss of separation, is the ATSP expected to intervene?
- Under what circumstances does the ATSP need to have the authority to cancel flight plan modifications of free-maneuvering aircraft?
- How much time is required for the CD&R technologies in order to enable free maneuvering in a safe manner?

- Does authority to maneuver for separation assurance extend to executing new strategic flight plans?
- Is controller expected to resume positive control in event of FD equipage failure?
- What division of roles and responsibilities is appropriate between the FD and the AOC in a flow rate constrained environment?
- Under what conditions should the ATSP intervene to assure compliance with airspace constraints?
- How can the AOC best support the flight crew in determining optimized trajectories?

Managing distributed & shared responsibilities

- Will flight crews and ATSP know at all times who has separation responsibility?
- If separation responsibility cannot be permanently transferred to the flight crew, under what conditions is responsibility delegated, shared, or retained by the ATSP?
- Can responsibility for separation assurance and authority to maneuver be defaulted to equipped aircraft or is case-by-case delegation required?
- Determine feasibility of distributed local traffic management planning through ground-based specification of constraints only vs. the need for a single management plan generated and executed by a single controlling authority.
- Can the ATSP be allowed to intervene and "force" an aircraft to meet its RTA if the ATSP thinks the RTA will be missed but could be made with a trajectory modification?

Workload mgmt, task balancing

- Can ATSP monitor some aircraft and actively control others with a manageable workload level?
- Will controller be able to move into and out of the active control loop without a performance loss?
- Does separation responsibility increase flight crew workload beyond an acceptable level?
- How do the heads-down traffic and constraint monitoring tasks affect crew performance?
- Can the flight crew assume separation responsibility without degradation in other duties?
- What feasibility limits are associated with authority to freely maneuver?
- Up to what level of traffic complexity is manual conflict resolution feasible?
- What level of dynamic density limits the ability of the ATSP to safely control mixed-equipage traffic?

Using automation

- Will failure of the ATSP to enter intent information into the DST compromise the usefulness of the DST to the ATSP?
- What FD planning capability is required to make free maneuvering useful to users?
- What coordination procedures between crews are required for self-separation?
- Will entering necessary intent information increase ATSP workload to an unacceptable level?
- What enhancements to the minimum FD DST functionality result in measurable benefits to the flight crew?
- What enhancements to the minimum ATSP DST functionality result in measurable benefits to the ATSP?

- How much do pilots need to understand about how conflict alerts and resolution advisories are created?
- Is adaptive automation technology required to ensure adequate ATSP and/or flight crew situation awareness?
- Determine the reductions in workload possible from intelligent agent technology in supporting controllers and flight crews to 1) maintain situation awareness, and 2) generate flight path adjustments when desired or needed.
- Is intelligent agent technology needed to prioritize hazards, either for crew alerting or for resolutions?
- Determine the need for resolution advisories compatible with crew goals and preferences, possibly through use of ownship intent inference and manual crew adaptation of decision support automation.
- How much do pilots and the ATSP need to know about how their DST is calculating conflict-free trajectories that satisfy ATSP constraints?
- Can the DST provide adequate assurance to the ATSP that all arrival plans are conflict free and robust to various failure modes?

Working within time horizons
- How late will the ATSP be able to intervene in complex situations and reliably resolve problems?
- Is there a maximum time horizon at which ATSP can be permitted to intervene for "autonomous operations" to be viable?

Managing constraints
- How do flight crews react in situations where performing separation assurance duties conflicts with meeting airspace and/or temporal constraints?
- How does the ATSP react in situations where the flight crew task of ensuring separation conflicts with meeting airspace and/or temporal constraints?
- How does the flight crew react when faced with situation of either missing the RTA or 'playing chicken" with other aircraft in a conflict situation?

Transferring responsibility
- Under what conditions is the ATSP likely to cancel free maneuvering authority for an aircraft?
- Is responsibility for separation or just authority to maneuver transferred to the flight crew?
- Will controllers ever give up authority without also being released from responsibility?
- What level of dynamic density and separation standards limit the ability of the ATSP to safely intervene?
- Is the transfer of responsibility and/or authority to the flight crew by exception or by consent?
- Determine feasibility of the assumption that "responsibility can never be transferred without acceptance by the receiving party".

Situation awareness and predictability
- How do the tasks of monitoring some aircraft and actively controlling others affect ATSP situation awareness?

- What is the impact of traffic predictability on ATSP performance?
- How certain must the ATSP be that new trajectories of free-maneuvering aircraft will result in a conflict in order to intervene?
- How do flight crews maintain awareness of intentions of other flight crews?
- How do controllers maintain awareness of the intentions of flight crews?
- How far in advance does the ATSP need to know of FD intent change before execution?
- How do aircraft-to-aircraft negotiations affect ATSP situation awareness?
- Will self-separating traffic reduce the predictability of traffic patterns to the ATSP?
- What effect does direct aircraft-to-aircraft communications have on situation awareness and time to resolve conflict?
- Will there need to be limits on how often a flight plan can be modified in order to prevent confusion or loss of situational awareness by the ATSP and/or Flight Crew?
- Airborne-generated trajectories may be conflict free but may differ from current controller procedures and may therefore be difficult to monitor. Will the ATSP be able to monitor aircraft on these trajectories?
- Does the ATSP need to monitor aircraft's progress toward meeting RTA?

Coordination and negotiation

- If transfer is by exception, how is intersector coordination performed, where the receiving controller had no say in the transfer?
- Does negotiation in conflict resolution increase flight crew workload beyond an acceptable level?
- Will different preferences in maneuvering strategies between the flight crew and ATSP cause difficulties in conflict resolutions?
- How does aircraft-to-aircraft negotiations affect ATSP workload?

"Data Exchange" categories

Content, frequency, accuracy

- Under what conditions does lack of intent knowledge of target aircraft make self-separation infeasible?
- What data is required by the ATSP to maintain adequate awareness of FD intent?
- What level of trajectory detail is required to adequately specify intent for self-separation and ATSP-assisted separation?
- What level of information detail (for weather, SUAs, target aircraft, etc.) is adequate for the FD to generate maneuver constraints?
- Define ADS-B message content required for concept feasibility.
- What data is required by the ATSP to support DAG-TM operations?
- What information is sufficient for the ATSP to maintain "big picture" that includes SS and non-SS aircraft?
- Identify need for TIS to increase surveillance range.
- Determine adequacy of projected horizontal and vertical position measurement accuracy.
- As the pilot is involved in both the preflight and execution phases of flight operations, what is the proper mix of information technology while avoiding information overload?

- What types of goals, preferences, and optimization criteria are best determined by the flight crew as opposed to the AOC?
- What information and time horizon are required by the AOC to assist in trajectory replanning?
- How much compatibility in constraint information is required between ATSP, FD, and AOC?
- How much information about the constraints of other aircraft, such as RTA, is needed for effective route planning and CD&R?

Data link mechanism
- How much latency is acceptable between the FD executing a new trajectory and the ATSP or other aircraft receiving the updated flight plan?
- Determine TIS navigation accuracy and latency requirements.
- How is NAS status information relayed to ATSP, AOC, and equipped/unequipped aircraft?
- Determine needed ADS-B reception rates as a function of range.
- Determine maximum acceptable communications systems latencies.
- How do equipped aircraft and ATSP get position, velocity and intent information about unequipped aircraft?
- How are AOC preferences for negotiating with other aircraft communicated to the FD?
- What is the mechanism by which other aircraft info (state, intent) is obtained by ownship? (e.g. ADS-B, data link from ground, 360 deg. Doppler radar)
- What maximum latency of NAS status information will allow aircraft to still conduct reliable in-flight replanning?
- Should NAS status information be continually broadcast throughout the NAS ("pushed") or sent on request ("pulled) by individual users?
- What data link mechanism is best suited for broadcasting flight plan modifications?
- What information content, accuracy, and update rates are required for aircraft to generate plan to maneuver efficiently around constraints?
- How are available arrival slots advertised and requested?

<u>**"Decision Support" categories**</u>

Overall functionality: FMS designed for autonomous operations
- What minimum DST functionality is needed on the FD for self-separation to be feasible?
- What method is required to ensure airborne CD&R is 100% effective (e.g., flight rules, intent inference, direct negotiation)?
- If the airborne CD&R method is not 100% effective, what method assures all conflicts are resolved?
- What DST capabilities are needed to make flight planning a more intuitive and simpler task?
- What commonality /differences exist in functional requirements of FD DST between free-maneuvering and ATSP-controlled modes of operation (I.e. CE's 5/7 and 6/8)?
- What additional FMS flight planning capabilities are needed to account for the airspace and flow rate constraints?

- What new FMS functions and data link capabilities are needed to permit constrained autonomous operations.

Overall functionality: ATSP DST designed for trajectory-oriented operations
- What minimum DST functionality is needed by the ATSP so that the ATSP roles in separation assurance and TFM are feasible?
- What FD and ATSP technology is needed to support the transfer of separation responsibility?

Interface (display, input, alerting)
- Determine user interface requirements, including placement of mod route on NAV display, use of the Flight Director, and operator-input devices such as touch pads.
- Determine crew alerting requirements and methods.
- What CDTI design attributes are required for autonomous separation assurance?
- What level of sensor noise and statistical error is allowable on the CDTI display of velocity vector and turn rate?
- How should FD alerting schemes be implemented to be compatible with other FD alerting systems?
- How are the flight crew and ATSP alerted to system faults?
- How should NAS status information be presented to the flight crew?
- How will flight crew and ATSP be alerted to potentially serious problems in meeting constraints?
- How are 4D constraints effectively conveyed to the flight crew and ATSP such that conformance to the constraints can be continually assessed?

Constraint management
- Will airspace and RTA constraints imposed on an aircraft that is maintaining self-separation allow sufficient degree of freedom to also accommodate user preferences in trajectory replanning?
- How do the flight crew and DST handle an overconstrained problem?

Intent information handling
- How can conflict resolution advisories be developed to be robust to errors in intent inferencing?
- How can the ATSP DST determine needed intent information of the ATSP without impacting ATSP workload?
- In conflict detection and resolution, how does the FD DST account for aircraft that do not conform to their broadcast intent?
- In conflict detection and resolution, how does the ATSP DST account for aircraft that do not conform to their broadcast intent?
- How can the airborne DST determine needed intent information of the ownship flight crew without impacting crew workload?
- How can the ATSP DST assist the ATSP in maintaining good situation awareness of continual changes in aircraft intent?

RTA-capable CD&R algorithms

- How much compatibility is required between ATSP and FD conflict detection logic?
- What level of accuracy is required for ascent, cruise, and descent trajectory prediction by the ATSP DST?
- What level of accuracy is required for ascent, cruise, and descent trajectory prediction such that autonomous separation is feasible?
- Determine advantages and appropriate ranges for state-vector-based separation assurance.
- Determine appropriate resolution strategies based on resolution degrees of freedom (speed, altitude, horizontal path), conflict approach angles and speeds, number of aircraft involved, separation capabilities of aircraft involved.
- What level of target aircraft intent information is needed in CD&R?
- What are the maximum acceptable rates for missed alerts and false alerts in conflict detection by self-separating aircraft?
- How can conflict resolution advisories be developed to be robust to execution errors?
- What are the maximum acceptable rates for missed alerts and false alerts in conflict detection by ATSP?
- How can a DST be developed to prevent maneuvers artificially biased to reduce minimum miss distance?
- How does trajectory adherence capability affect optimal trajectory determination by the DST?
- How far in advance can a conflict be predicted to occur with enough certainty to take action?
- Determine the need for various types of resolutions based on operator goals (optimal efficiency, cooperative, explicit coordination, implicit coordination, maximum safety).
- For each type of resolution, determine: 1) appropriate event horizons, 2) single trajectory vs. range advisory, 3) automatic vs. manual facilitated by DST, 4) need for intent transfer, and 5) FMS execution vs. manual control.
- Will the ATSP have sufficient degree of freedom to intervene for separation assurance with aircraft descending on idle thrust (high-energy) descents?
- How will conflict resolutions accommodate inflexible near-term RTA constraints?
- For flow-constrained arrival situations, can a conflict-free solution for all aircraft always be determined?
- Determine best conflict avoidance strategies while meeting RTA.

User preference handling

- How should trajectory constraints and user preferences be specified for use by the DST?
- What additional optimization criteria, other than cost function, can be accounted for by the FD planning capability?
- How does the FD DST balance user preference accommodation and far-term conflict avoidance in developing an optimal trajectory?

Traffic situation complexity prediction (ATSP)

- What ATSP DST capabilities are needed for traffic complexity prediction and alerting?

"Procedures" categories

Airborne autonomous operations

- What are the FD and ATSP procedures allowing the autonomous execution by equipped aircraft of new trajectory/flight plan without requesting clearance?
- What clearance limits should accompany the authority to freely maneuver?
- What level of ATSP concurrence is required for self-separating aircraft to change trajectories: none, trajectory change not vetoed, or active concurrence of trajectory change?
- What FD procedures should be used for negotiating conflict resolutions other aircraft?
- Should aircraft exercising self-separation authority be required to delay execution of a new trajectory to allow ATSP the opportunity to review and possibly deny the new trajectory?
- What processes are followed when the flight crew determines it cannot meet the RTA before and after the RTA freeze horizon?
- What changes in FD procedures are needed after the RTA freeze horizon is reached?
- How does the user formulate preferences for route planning?
- How much coordination is needed between FD and AOC in preference determination and actual route planning?

Mixed-equipage operations

- What FD and ATSP procedures should be used for conflicts involving aircraft with mixed levels of self-separation capability?
- How many "levels" of equipage are acceptable (e.g., will users be able to make a relevant distinction between multiple levels of aircraft equipage, especially if there are more than two?)

Trajectory-oriented ATSP

- What intersector and intrasector ATSP coordination procedures should be used to support trajectory-oriented ATSP operations?
- What procedures are necessary when a conflict occurs near a sector boundary?
- What intersector and intrasector ATSP coordination procedures should be used to support trajectory-oriented ATSP operations?

Intervention

- Under what conditions should the ATSP intervene to resolve a conflict between aircraft with responsibility for self-separation?
- What ATSP procedures should be used for intervention to resolve a conflict?

Transfer of responsibility

- What ATSP procedures should be used for delegation of maneuver authority to the flight crew?
- What FD and ATSP procedures should be used to transition aircraft between self-separation and ATSP-controlled operations (either direction)?
- What are the appropriate conditions under which separation responsibility should be transferred, either implicitly or by explicit instruction?

– What FD and ATSP procedures should be used to transition aircraft between self-separation and ATSP-controlled operations (either direction)?

Degraded-mode operations
– What FD and ATSP procedures should be used to manage degraded modes of operation (e.g., lost communications, failed DST, failed surveillance, etc.)?
– How does the ATSP handle loss of communication or surveillance for one or more aircraft?
– What procedures are needed to ensure safety in the event of communications failure?

Situation awareness maintenance
– Determine appropriate procedures for controller intervention and controller situation awareness maintenance.
– What FD and ATSP procedures are necessary to ensure the process of developing and executing conflict resolution trajectories can be completed without disruption?

Constraint management
– How are situations handled when no solutions are available that either are conflict free or meet all constraints?
– Under what situations does the ATSP need to intervene with additional constraints (e.g. temporary metering through hole in line of thunderstorms)?

Traffic situation complexity
– In multiple-conflict situations, what procedures should be used by each participant (all flight crews and ATSP) in conflict resolution?
– How many aircraft can simultaneously initiate maneuvers in a constrained environment such that separation assurance and situation awareness are maintained?

"Safety" categories

CNS failures / redundancy
– What will be the impact of losing GPS?
– What will be the impact of losing ADS-B?
– How is system safety affected by self-separating aircraft that experience equipment failure?
– What CNS data sources and capabilities require redundancy to maintain or improve system safety?
– Identify mission-critical system elements and unacceptable failure modes (e.g., ADS-B fail-on).
– Determine limits of concept feasibility using ADS-B surveillance only.

Automation failures
– What new hazard modes are created with the implementation of DAG-TM and how are they mitigated?
– How should safety levels be quantified in the process of changing separation standards, procedures, hardware, and software?

- How is the maintenance of safety under RVSM standards verified?
- What is the relationship between additional levels of redundancy and proposed reduced separation standards?

Decentralized authority
- Can responsibility for separation assurance for equipped aircraft be permanently transferred to the flight crew with no degradation in safety?
- How will system safety by affected by decentralizing traffic management where no individual has overarching authority to mitigate complex traffic situations?

Non-compliant participants
- Determine robustness of system to: single-aircraft noncompliance, two-aircraft noncompliance, ADS-B transmit/receive failures, CPDLC failures, primary/secondary radar failures, NASWIS failure, TIS failure.
- Will trajectories be robust to failures of some aircraft to accurately execute their broadcast intent?

"System Performance" categories

Traffic situation complexity
- How would aircraft segregation based on equipage affect NAS operations?
- Determine ability of controller/traffic management coordinator to lower traffic complexity through hot spot prediction and prevention through selective controller intervention and/or information transfer to user for voluntary rerouting.
- How should airspace complexity be predicted and quantified?

Weather system severity
- How is system performance affected by weather systems of various types, extent, and severity?

Decentralized decision making
- What global problems can occur with many individual aircraft generating self-optimal trajectories?

Stability in competition
- How does competitiveness between carriers impact AOC/pilot negotiations?
- At a system level, determine whether all stakeholders will have the necessary incentives to develop and maintain the system.

"Benefits" categories

Communication / coordination

- Determine the potential for reductions in clearances, especially voice communication clearances.
- Determine potential for reduction in intersector coordination between controllers.
- Quantify the ability of users to modify trajectories without the need for a contract with the ATSP.

Schedule adherence

- What benefits are obtained by providing the AOC a DST for real-time schedule optimization?
- Determine improvements in schedule adherence and efficiency based on limits of RTA-meeting capability at boundaries and fixes.
- Quantify the ability for users to recover schedule integrity in the presence of disruptions such as weather or local traffic management constraints.
- Determine abilities of aircraft to replan and/or recover schedules in face of changing conditions, such as weather and dynamic SUAs.

Distributed workload

- Estimate number of aircraft per controller as function of percentages of free maneuvering vs. basic-equipage aircraft and traffic complexity.

Capacity / efficiency

- What are the cost-benefit issues applicable to general aviation, business aviation, the military, and airlines?
- Quantify the potential of free maneuvering to improve system capacity and airline fleet efficiencies.
- Determine throughput limits by use of free maneuvering with use of RTAs at boundaries and fixes for various types of constraints.
- Estimate changes to ground-based services that may be afforded by the concept, including the capability to improve efficiency of ground-based services and the ability to redesign airspace for increased efficiency.
- Determine flight efficiencies through minimization of fuel consumption for metering scenarios and through minimization of fuel and time for scenarios that do not involve metering.
- Estimate system benefits resulting from reductions in separation minima (protected zones), if these reductions are found to be feasible.

Appendix. Operational Needs Statements Table

Operational Needs Statements – Flight Planning Service Area

The following operational needs statements are addressed by CE-5, En Route Free Maneuvering for User-Preferred Local TFM Conformance. The numbers provide a trace to the matrix of operational needs statements supporting the AATT ATM/OPSCON.

ONS #	ONS Text
1_386	... 4D weather information (winds, temperature, turbulence, storm cells, icing, etc), combined with analysis of trajectory predictions to determine the flights that are possibly affected, will allow users (FD / AOC) to more effectively plan and re-plan various flight operations.
1_422	The most obvious user benefit is a reduction in the per-flight direct operating cost that every user operating under IFR can obtain through real-time optimization of their flight trajectory.
2_100	By the year 2000, users with properly equipped aircraft are able to file user-preferred routes from departure airport Standard Instrument Departure to arrival airport Standard Terminal Arrival Route or from airport-to-airport.
2_105	Aircraft equipped with "self-contained" navigation may file for user-selected waypoints independent of airways and NAVAIDs.
2_110	All users can evaluate their planned flight against system constraints such as hazardous weather, Special Use Airspace, flow restrictions (airspace facility demands), and infrastructure outages in advance of the flight.
2_115	The advance knowledge of conditions along the proposed route allows the flight planner to anticipate possible reroutes that may be needed after departure.
2_130	Operators equipped with data-link are able to load a data-linked flight plan directly into the FMS.
2_135	By the year 2000 GA users are able to probe flight plans against system constraints.
2_150	significant changes in the planning data available to users, and in the flight plan itself. ... planners and service providers have automated access this information from the continuously and automatically updated NAS-wide information system.
2_160 2_280	today's flight plan is replaced by a flight profile. This profile can be as simple as the user's preferred path, or as detailed as a time-based trajectory that includes the user's preferred path and preferred climb and descent profiles.
2_165	The flight profile is a part of a larger data set called the flight object. This is a data set which is available throughout the duration of the flight, both to the user and to service providers across the NAS.
2_175	For a flight operating under instrument flight rules (IFR), the flight object can be a much larger data set, including a preferred trajectory coordinated individually by the user, and supplemental information such as the aircraft's current weight, position, runway preference, or gate assignment
2_180	Flight object information can be updated by the user or service provider throughout the flight.
2_185	flight plan process currently used by service providers will be enhanced to provide

ONS #	ONS Text
	a collaborative interaction with the user. This interaction will create dynamic, event-driven user-preferred trajectories for individual flights.
2_210	Accept and accommodate flight plans for user-preferred routes from:- departure airport Standard Instrument Departure (SID) to arrival airport Standard Terminal Arrival Route (STAR) - airport-to-airport.
2_245	Provide voice and electronic messaging support to users for clarification of flight planning information.
2_255	Prepare and file a flight plan with the service provider.
2_260	If user has AOC or AOC-like capability, perform a probe for active or scheduled SUA, weather, and airspace and flow restrictions in preparing a flight plan.
2_270	The flight planning process by 2005 will be based upon the enhancement of the near-term systems capabilities resulting from the "real time" sharing of information regarding the NAS and system demand.
2_285	flight profile ... This action initiates the automatic creation of a flight plan that contains either the user's preferred route of flight or a more detailed time-based flight trajectory.
2_290	For all users, an enhanced flight plan is available that provides a much larger data set, including preferred trajectory, aircraft weight, runway preference for departure and arrival, gate assignment, and cross-border issues for international flights.
2_300	By 2005 the flight planner will interact with the NAS-wide information system to create a flight profile. This action initiates the automatic generation of a flight object containing either the user's preferred flight path or a more detailed time-based flight trajectory.
2_305	As conditions change during the planning phase, or during the flight, the planner continues to access the NAS-wide information system to determine the impact of the changes on the flight.
2_315	Information such as runway preferences and aircraft weight, or information to support flight following can be added during the planning phase or during the flight.
2_320	As the planner interactively generates the flight profile, information regarding current and predicted weather conditions, traffic density, restrictions and status of SUAs is available
2_325	When the profile is filed, it is automatically checked against these conditions and any static constraints such as terrain and infrastructure advisories.
2_330	Potential problems are automatically displayed to the planner for reconciliation. Upon filing, the flight object is updated as necessary, along with all affected projections of NAS demand.
2_360	As conditions change during the planning phase or during the flight, the user is able to interactively determine the impact of the changes on the flight and modify the flight plan as necessary
2_405	Interactive flight planning capabilities will have been fully implemented.
2_425 2_415	Interactive flight planning is available for pilots of properly equipped aircraft to aid in filing airport-to-airport flight plans with user-preferred routings.
2_430	The DoD user has real-time interactive flight planning capabilities, which enable

ONS #	ONS Text
	more effective flight planning with respect to NAS resources.
2_455	Interactive flight planning information is available to all GA pilots.
3_185	continuous updating of the flight object improves real-time planning for both the user and the service provider. ... improves the effectiveness of ongoing traffic management initiatives and the collaborative decision making
3_205 4_285 5_335 6_220	Approve or deny proposed flight plan changes, except those needed for cockpit self-separation when that responsibility has been transferred to the flight deck.
4_280	Status information concerning the NAS infrastructure components that support arrival and departure operations is shared with the flight deck.
5_490	Updated charts, current weather, SUA status, and other required data will be up-linked (or data-loaded) to the cockpit allowing for better strategic and tactical route and altitude planning. Data link will also allow the aircraft crews and the service provider specialists to see the same weather and alerts.
5_870	Routes are probed for flow constraints prior to filing, resulting in fewer reroutes.
5_875	FMS equipage, including coupled navigation capabilities, also allow for more efficient flight planning by the AOC.
6_150	reduced separation minima and dynamic management of route structures will help the user formulate and request a preferred flight profile.
7_175	users will be better able to plan their flight ... and to minimize congestion or possible delays due to the ... information made available by the NAS-wide information system.
7_575	User flexibility is significantly expanded by advance information about demand and capacity. ... revising their plans in a timely manner.

Operational Needs Statements – Separation Assurance Service Area

The following operational needs statements are addressed by CE-5, En Route Free Maneuvering for User-Preferred Separation Assurance.

ONS #	ONS Text
1_225 5_135	Separation assurance remains the responsibility of the service provider. However, that responsibility is shifted to the flight deck for specific operations.
1_235	ADS-A A different form of ADS, designed to support oceanic aeronautical operations, based on one-to-one communications between aircraft providing ADS information & a ground facility requiring receipt of ADS reports.
1_238	Retransmit position reports from all pertinent aircraft from the traffic information service back to the cockpit.
1_330	avoidance of convective weather will be greatly improved as the weather tools are integrated with the decision support tools.
1_360	Assure that users maintain required separation, based on pre-defined separation standards, except for specific operations when responsibility is shifted to the flight deck.
1_375 4_370	Through a data link to the properly equipped cockpit, provide users- routine communications- updated charts, current weather, SUA status, and other data- basic flight information services, including forecast weather, NOTAMs, and hazardous weather warnings- airport information, including Runway Visual Range (RVR), braking action and surface condition reports, runway availability, and wake turbulence and wind shear advisories - clearances and frequency changes in the form of pre-defined messages.
1_395 3_265	Assign cockpit self-separation responsibility to flight crews "when operationally advantageous".
1_405	Provide self-separation between the user aircraft and other aircraft, terrain, and obstacles for specific operations when responsibility is shifted to the flight deck from the service provider.
1_440 5_515	Air safety has been increased through the implementation of conflict detection and resolution tools, the inclusion of the flight deck in some separation decision-making, and greatly enhanced weather detection and reporting capabilities.
4_220	Satellite-based position data, broadcast by properly equipped aircraft, are used in cockpit traffic displays to increase the pilots' situation awareness for aircraft-to-aircraft separation. These avionics allow an increasingly frequent transfer of responsibility for separation assurance to the flight deck for some types of operations.
4_221	The rules, procedures, and training for these types of shared separation assurance need definition
4_310 4_350	When appropriate in low-density areas, clear properly-equipped aircraft for free maneuvering.
4_311	Properly equipped aircraft are given authority to maneuver as necessary to avoid weather cells, or to follow such aircraft using self-spacing procedures.
4_470 5_555	separation assurance has undergone changes in the following areas: aircraft-to-aircraft separation, aircraft-to-airspace and aircraft-to-terrain/obstruction separation, and

ONS #	ONS Text
6_345	departure and arrival planning services.
4_485	The increased use of this distributed responsibility is made feasible through improved traffic displays on the flight deck, combined with appropriate rules, procedures, and training to support the new roles and responsibilities of the users and service providers.
4_770 5_355	Free maneuvering operations in low-density areas is being performed.
4_775	High density areas still require the oversight from ATC for sequencing and primary separation assurance
4_780 5_810B	in the denser environments some cockpit self-separation is assigned to the flight crew by ATC when operationally advantageous.
4_795	all DoD NAS users are equipped with augmented satellite-based navigation aids, data link, ground proximity warning systems (GPWS), cockpit display of traffic and weather information and on-board collision avoidance.
5_140 1_265	improved situation awareness in the cockpit, enabled by the CDTI display and improved navigation precision, allows some separation tasks to be performed by the flight crew
5_235 5_440	Additional intent and aircraft performance data is provided to decision support systems, thus improving the accuracy of trajectory predictions. This information is combined and presented on the service provider's display.
5_295	Improved decision support tools for conflict detection, resolution, and flow management allow increased accommodation of user-preferred trajectories, schedules, and flight sequences.
5_360 6_230	When operationally advantageous in high-density areas, clear properly equipped aircraft for cockpit self-separation.
5_415	Develop reduced or time-based separation standards, based on technology and aircraft capability, to increase system capacity and safety.
5_430	The use of satellite-based navigation and surveillance data will not only increase on-board capabilities ranging from cockpit traffic and enhanced collision avoidance logic, but will also be used by ground-system automation for enhanced conflict probe and alerting.
5_520 5_580	Improving the provider's ability to identify conflicts will also reduce the number of occasions when there is intervention, allowing the user to fly the trajectory proposed with higher frequency.
5_545a	separation assurance services are provided in the en route area
5_550	As in the departure and arrival operations, increased decision support allows significant improvement in en route separation assurance.
5_560	there will be improved coordination between the service provider and the flight deck to aid the flight in weather avoidance.
5_565	improved information available from common weather sources, service providers will be more effective in controlling aircraft in airspace that contains hazardous weather and in providing weather advisories to pilots.
5_571a	Users assume responsibility for separation in low-density airspace, provided they are suitably equipped.

ONS #	ONS Text
5_575	Decision support systems will assist in conflict detection and the development of conflict resolutions.
5_785	Airlines and high-end GA frequently perform free maneuvering operations in low density areas
5_790	high density areas still require the oversight from ATC for sequencing and primary separation assurance.
5_845	In en route airspace, the use of moving maps for CFIT avoidance, CDTI, and weather depiction has begun, albeit, the user application stressed may be different.
6_155	Most aircraft navigate using a global satellite navigation system whose improved accuracy will generate the required safety for reduced separation standards.
6_285	Perform some separation and merging activities that were previously performed by the service provider.
6_290 6_320	Provide increased position awareness of aircraft for monitoring and separation of flight progression through automatic dependent surveillance.
6_470	Cockpit self separation provides immediate situation assessment, communications (i.e., air to air), and decision making.
6_475	This tighter cockpit self separation decision/control loop could allow greatly reduced separation standards
6_520	Use of cockpit self-separation and free maneuvering operations are being performed in more complex situations, such as merging.

References

1. AATT Project, *Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM) Version 1.0,* September 30, 1999.

2. RTCA Inc*., A Joint Government/Industry Operational Concept for the Evolution of Free Flight,* August 1997.

3. NLR (Netherlands), *Overview of NLR Free Flight Project 1997-1999,* NLR-CR-2000-227, May 2000.

4. Ballin, M. G., Wing, D. J., Hughes, M. F., and Conway, M. R., *Airborne Separation Assurance and Traffic Management: Research of Concepts and Technology,* AIAA Paper 99-3989, August 1999.

5. RTCA Inc., *Concept of Operations (Application Description) for Airborne Conflict Management: Detection, Prevention & Resolution,* Prepared by: RTCA Special Committee 186, WG-1, Conflict Detection and Resolution Subgroup, July 6, 2000.

6. MITRE Corp., *TCAS: The Traffic Alert and Collision Avoidance System,* http://www.mitre.org/pubs/showcase/tcas/tcas.html

7. Volpe National Transportation Systems Center, *Technical Performance Metrics Description Document for NASA AATT,* November 1, 1999.

8. AATT Project, *Research Plan for DAG-TM, Version 1.01,* September 30, 1999.